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Tam

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(54) **CAMERA MODULE WITH A MOLDED ENCLOSURE CONTAINED IN A FLEXIBLE SUBSTRATE**

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- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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- (60) Provisional application No. 61/872,475, filed on Aug. 30, 2013.

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H01L 27/146 (2006.01)
H04M 1/02 (2006.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

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See application file for complete search history.

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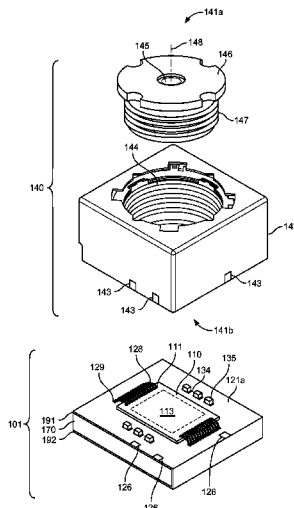
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(57)

ABSTRACT

Systems and methods of manufacturing compact camera modules for use in electronic device are provided. The camera module includes a lens housing and a substrate assembly. The substrate assembly includes a flexible substrate wrapped around a molded enclosure. The optical image stabilization components for the camera module may be enclosed within the molded enclosure.

18 Claims, 22 Drawing Sheets



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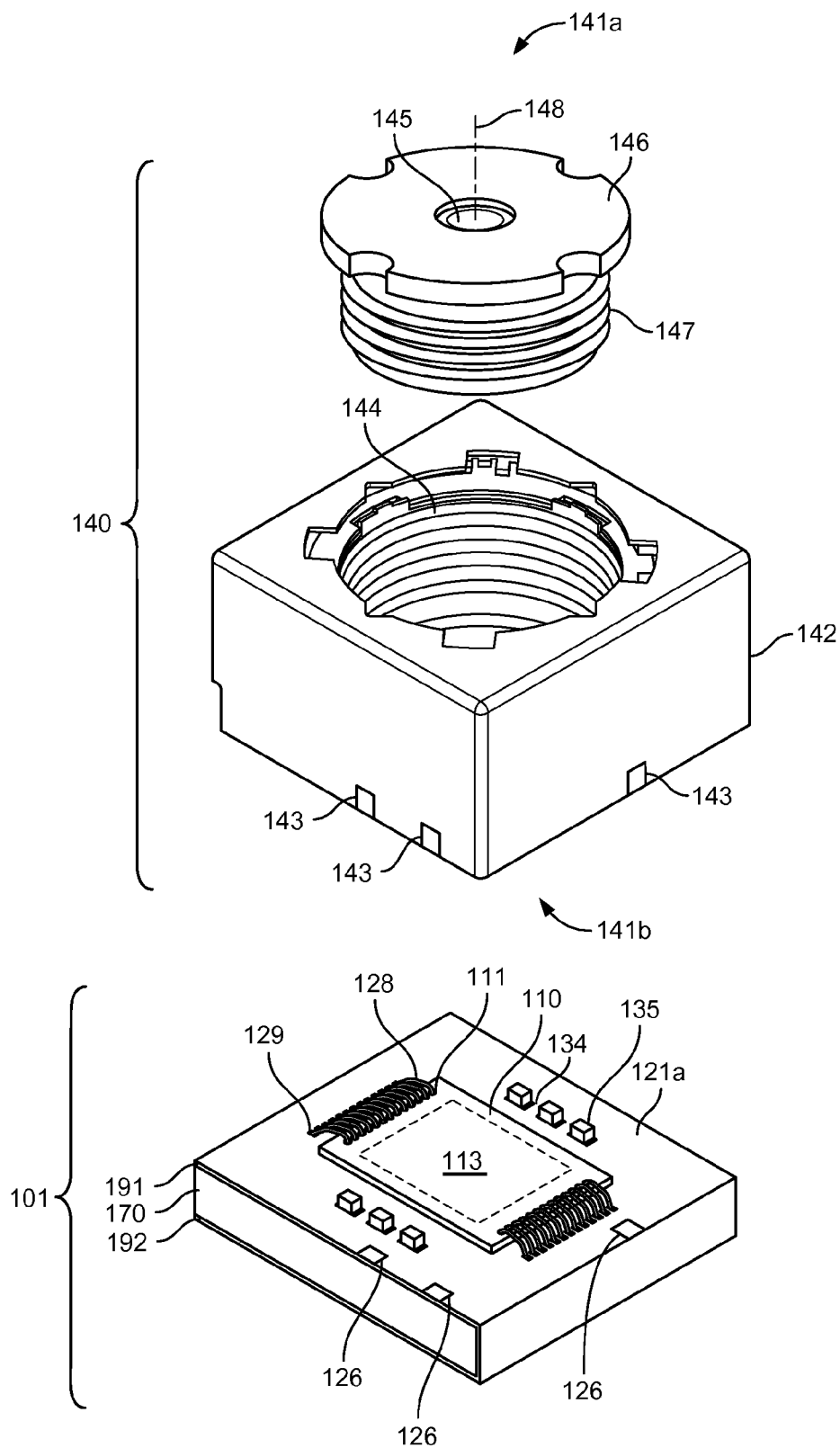


FIG. 1

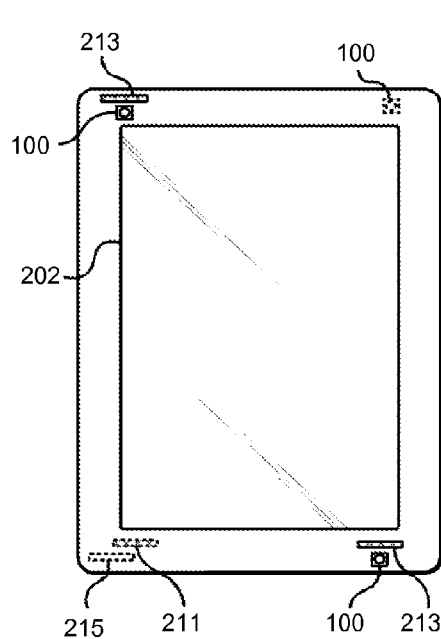


FIG. 2A

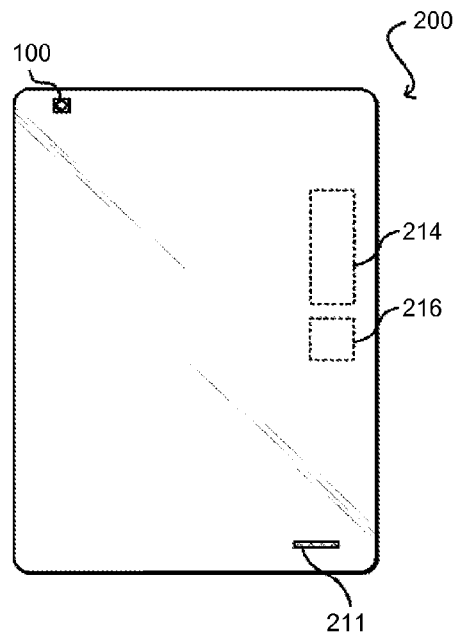


FIG. 2B

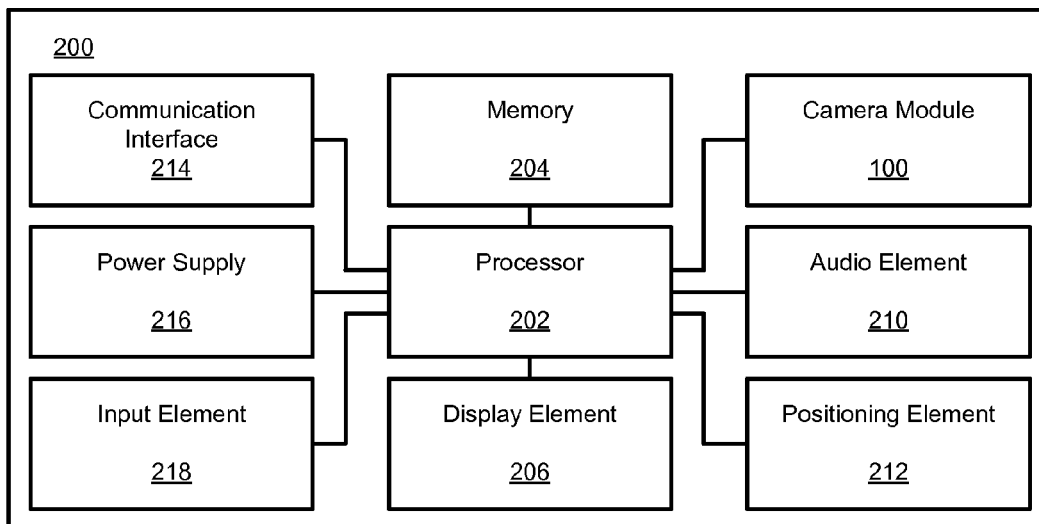


FIG. 3

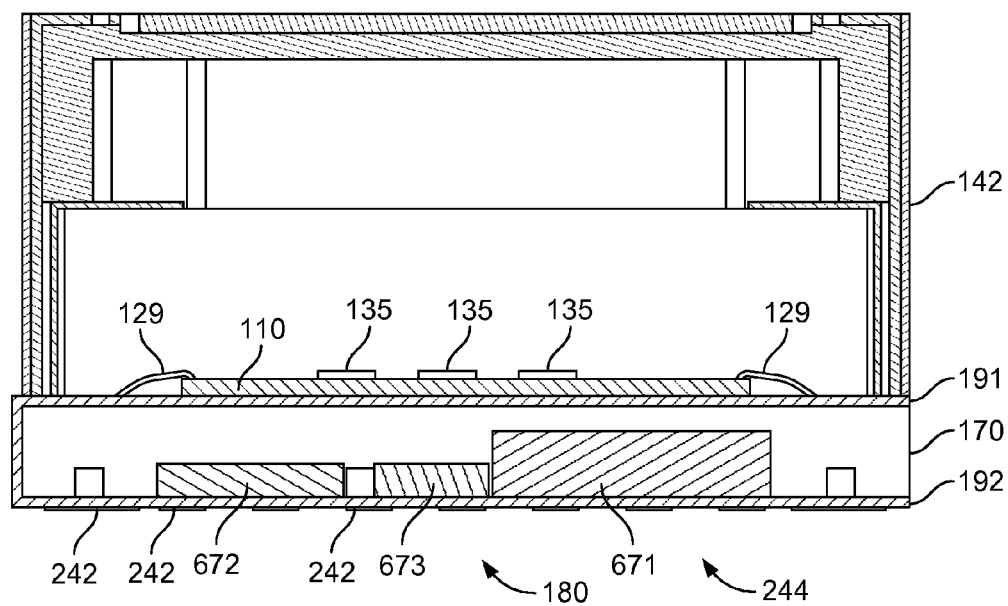


FIG. 4

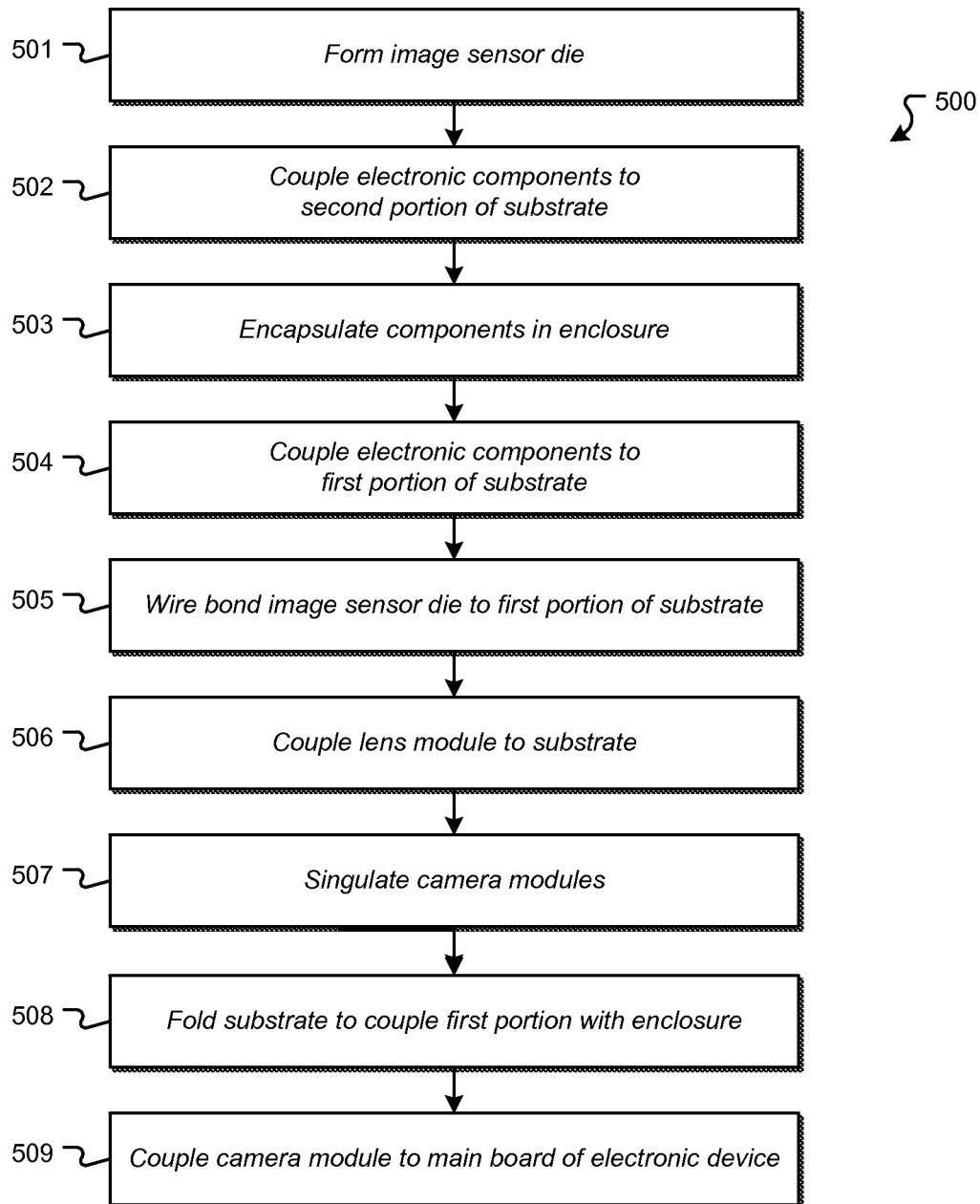


FIG. 5

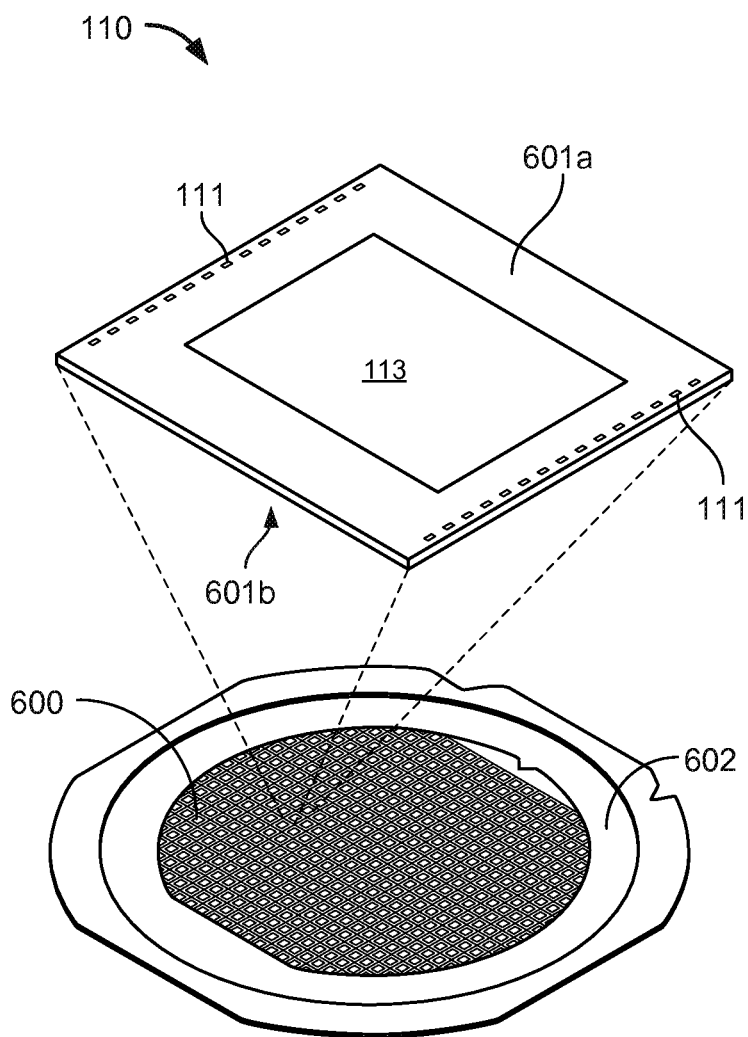


FIG. 6A

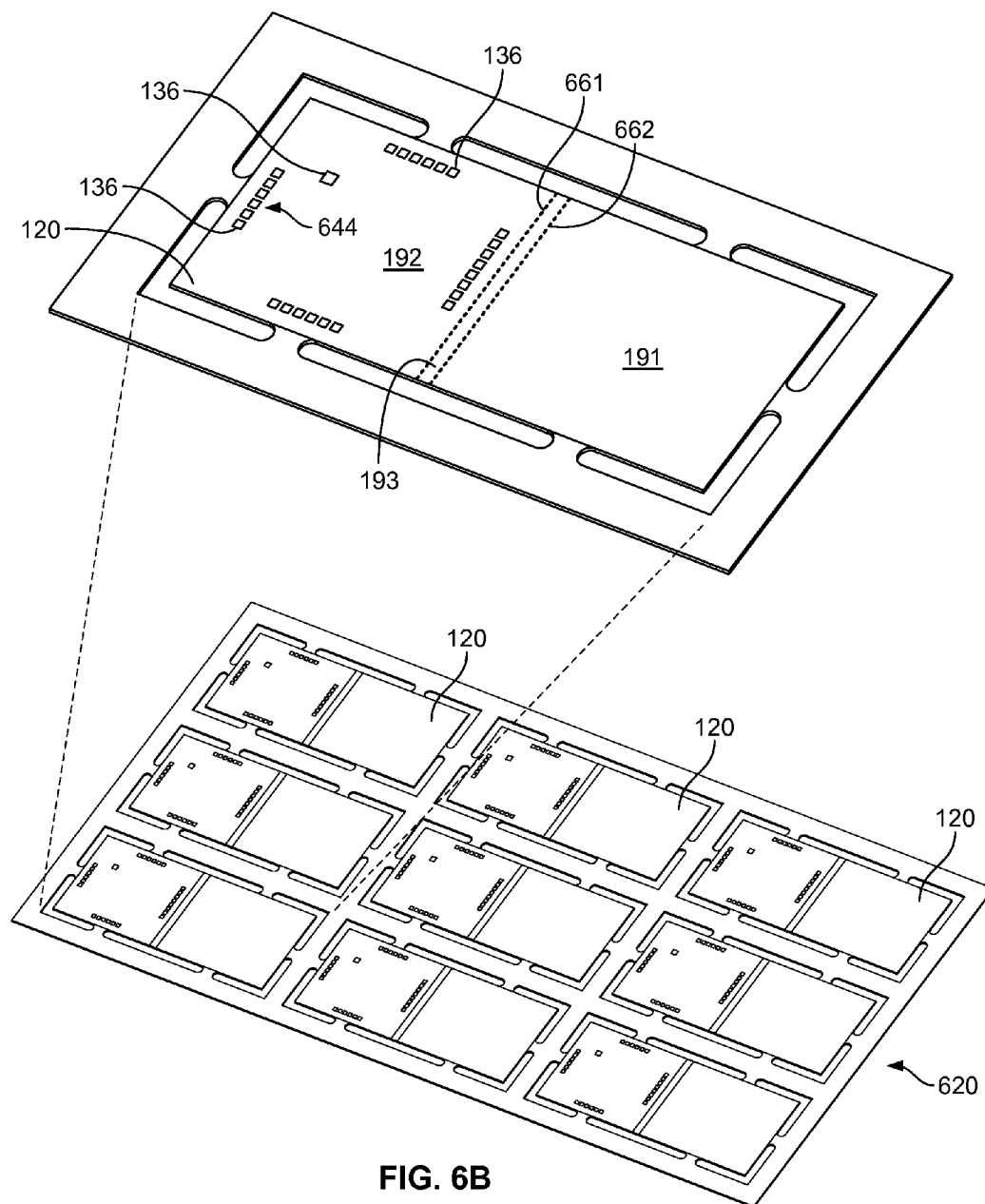


FIG. 6B

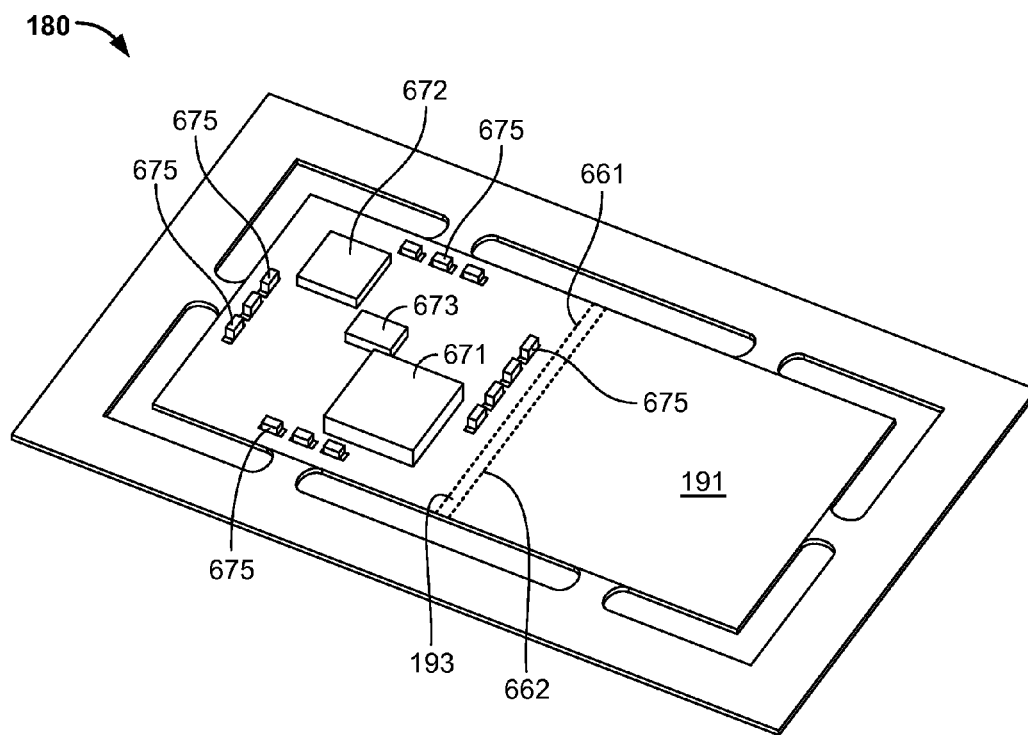


FIG. 6C

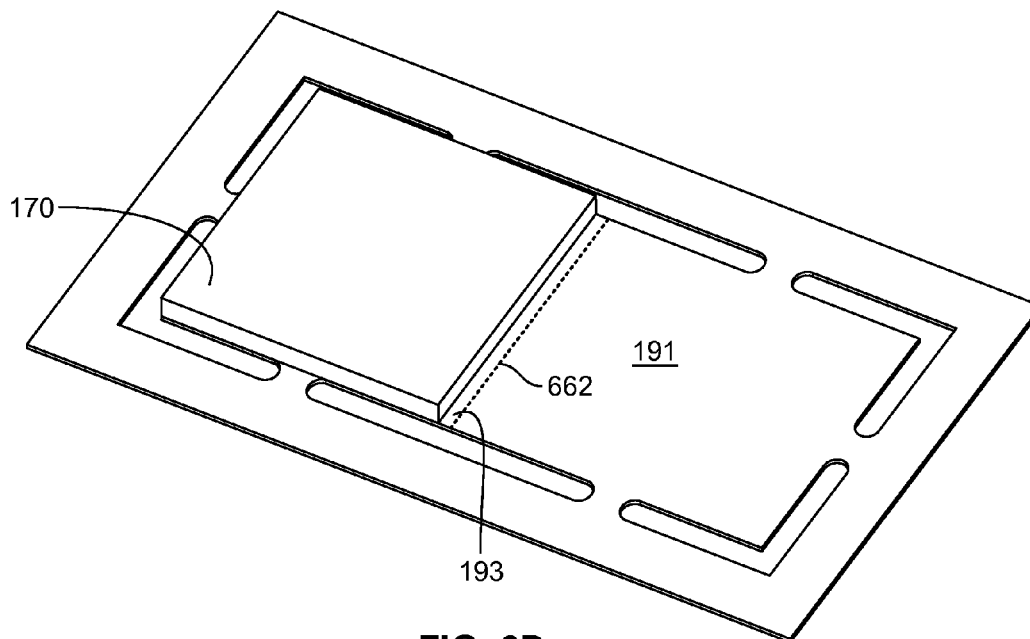


FIG. 6D

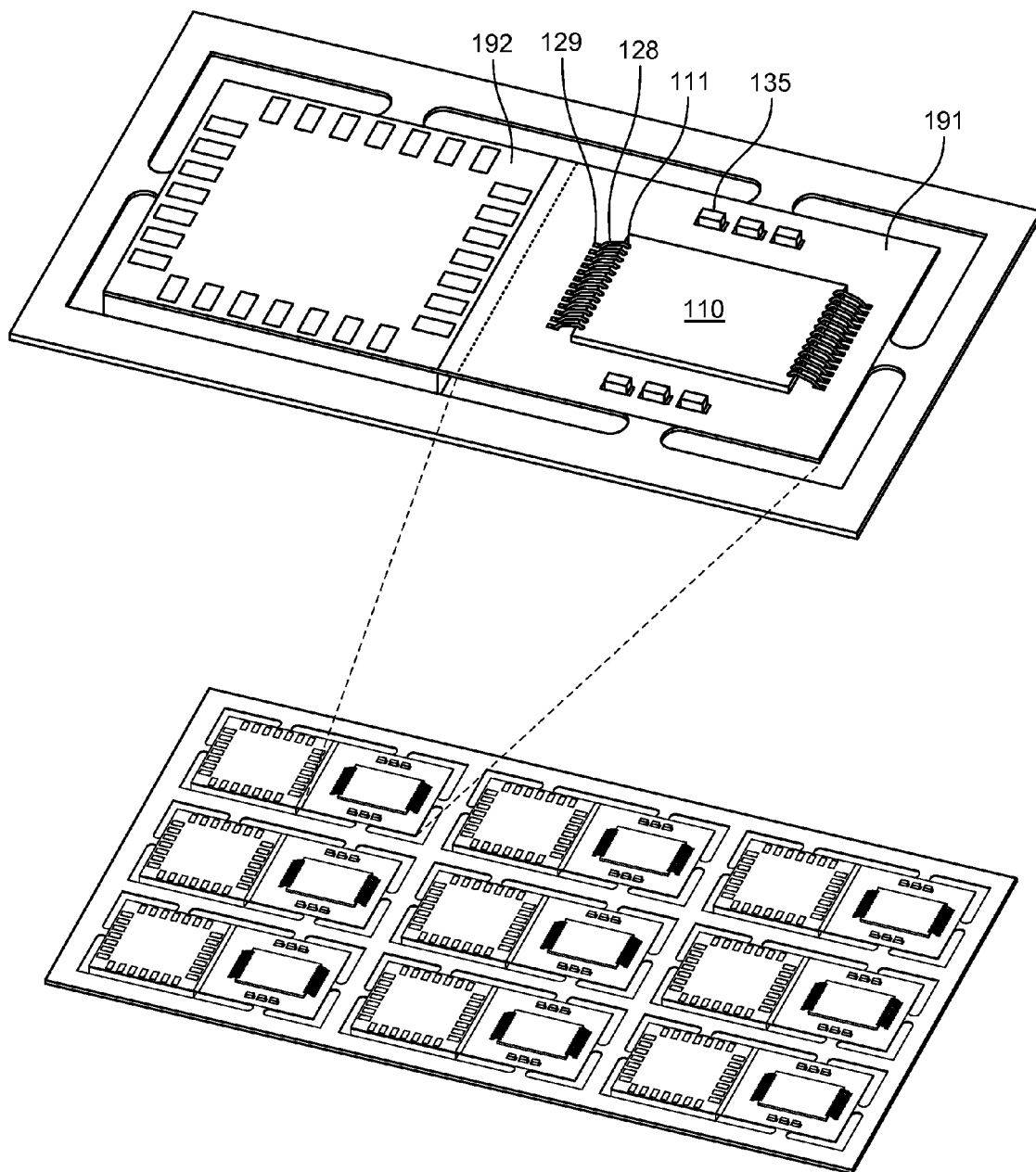


FIG. 6E

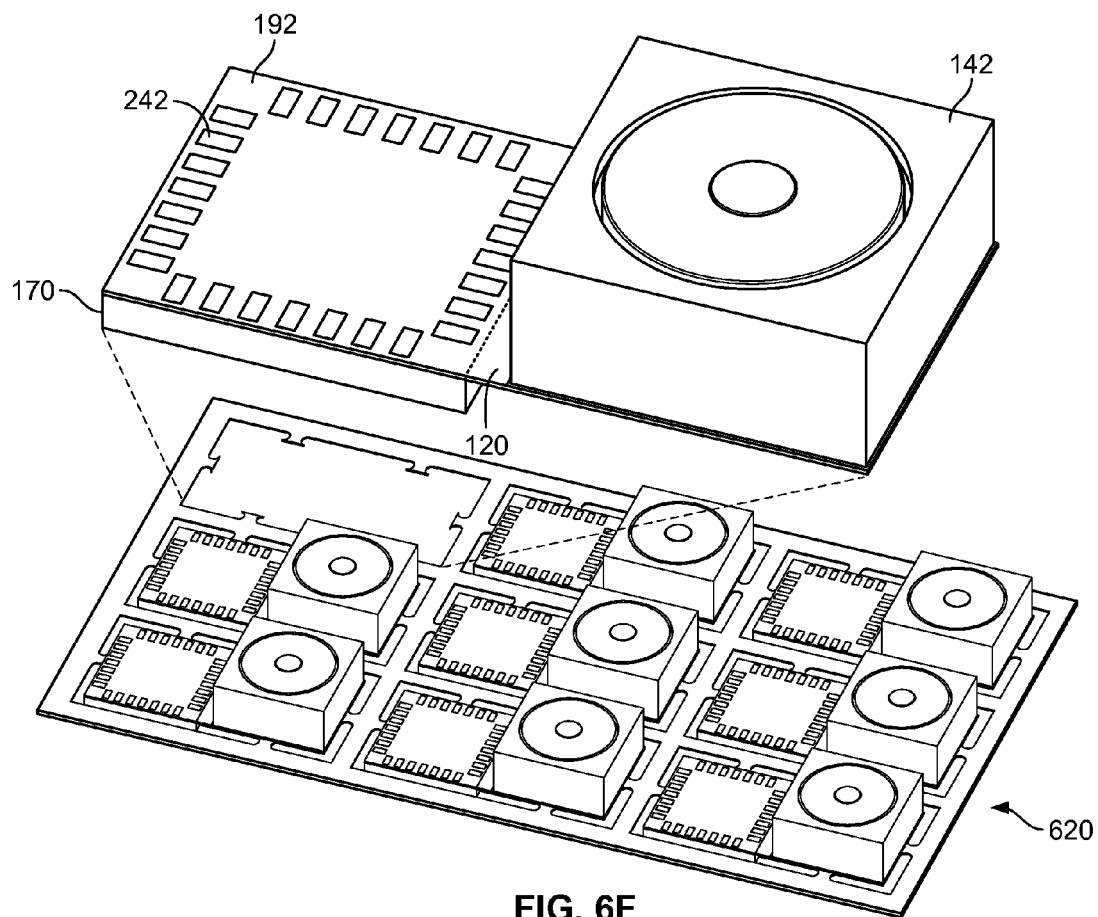


FIG. 6F

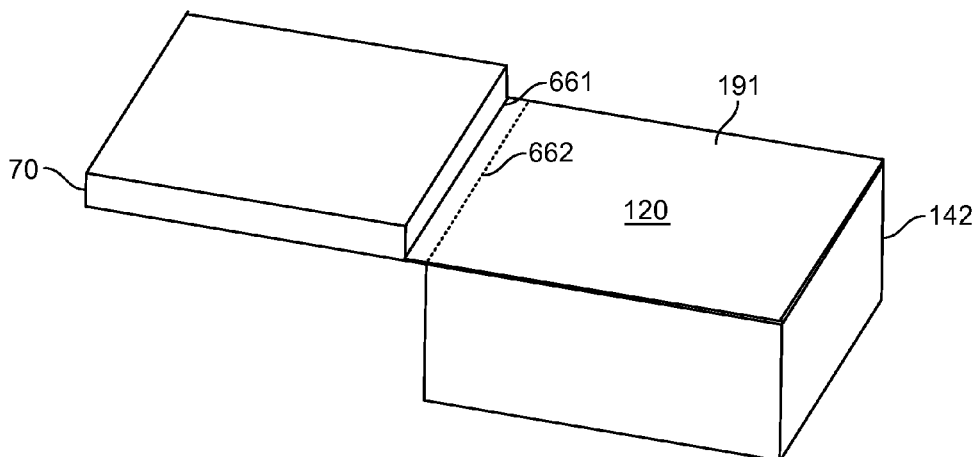


FIG. 6G

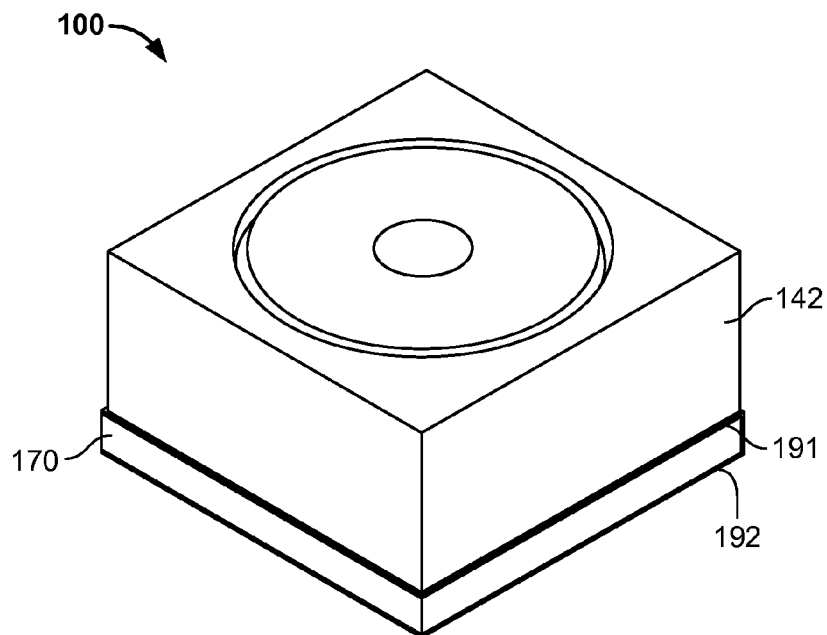


FIG. 7A

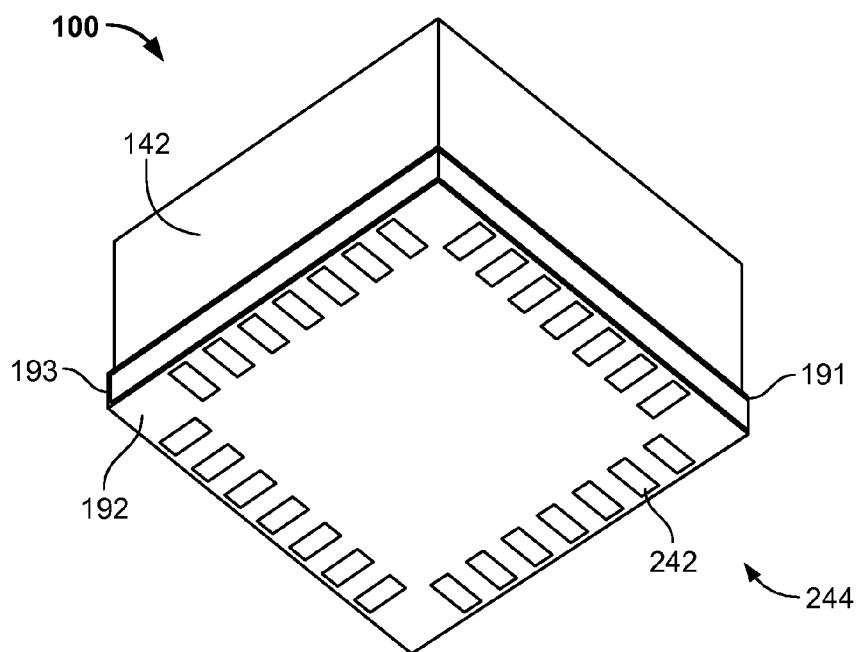


FIG. 7B

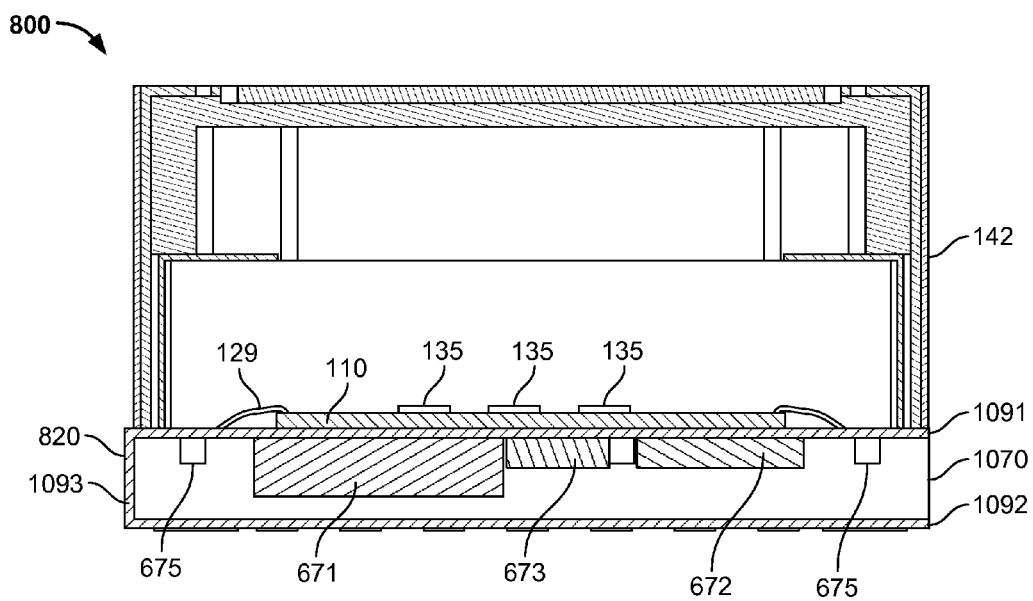


FIG. 8

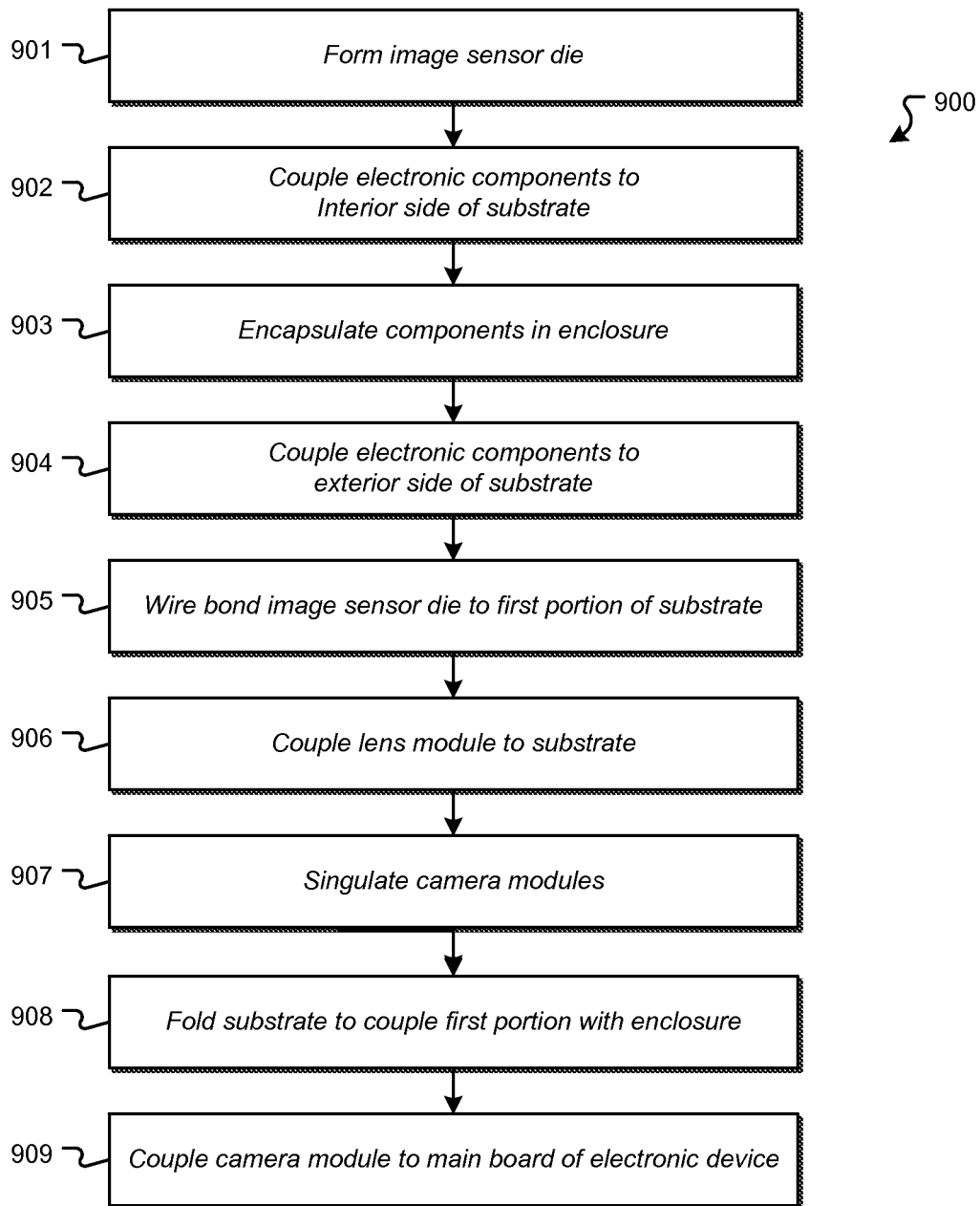


FIG. 9

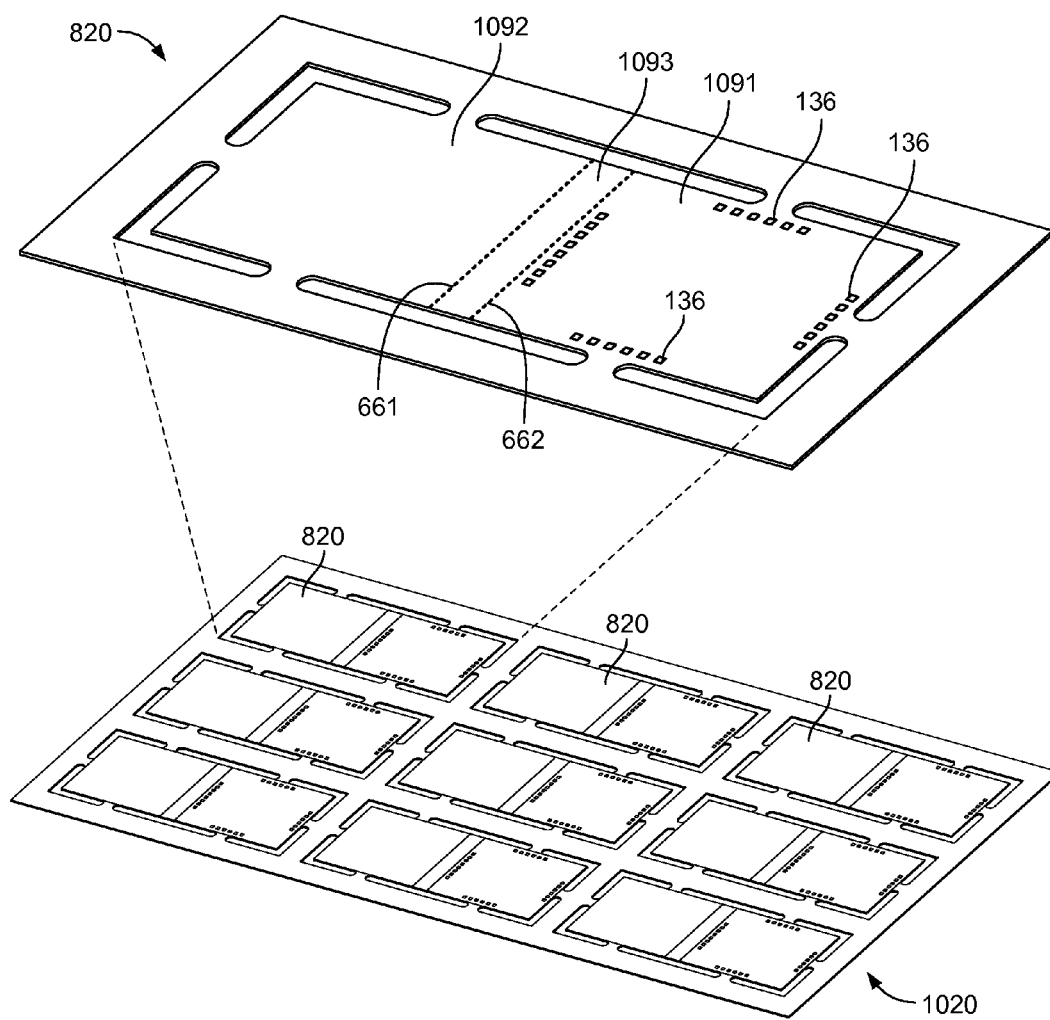


FIG. 10A

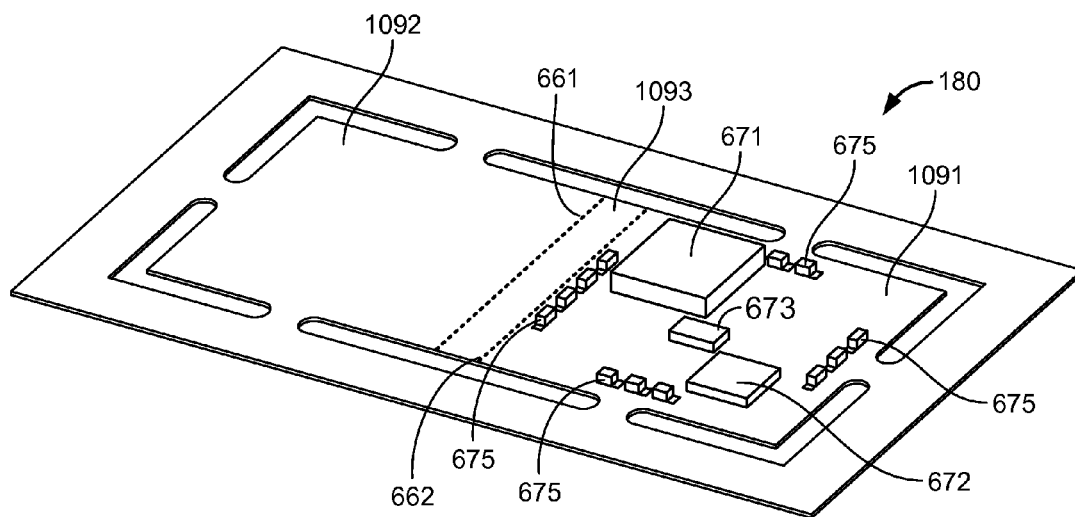


FIG. 10B

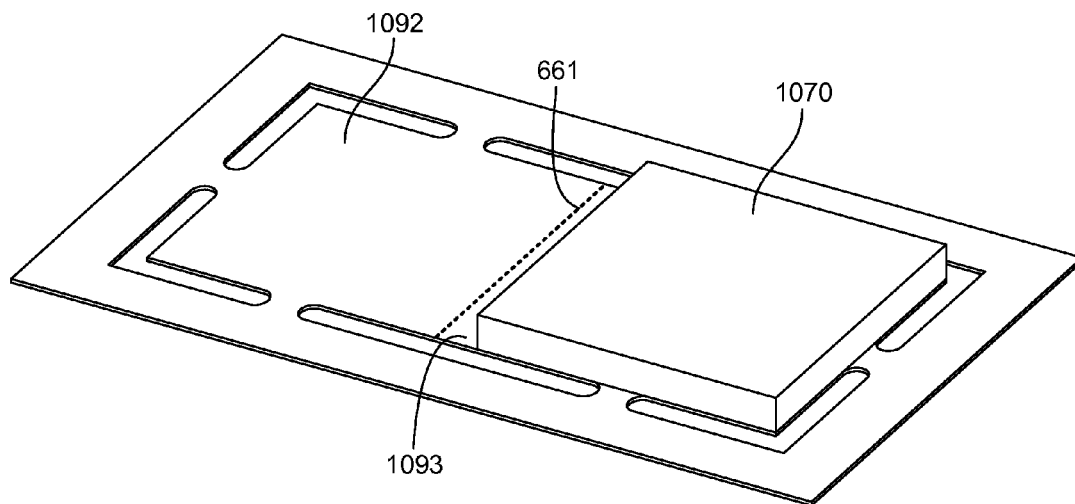


FIG. 10C

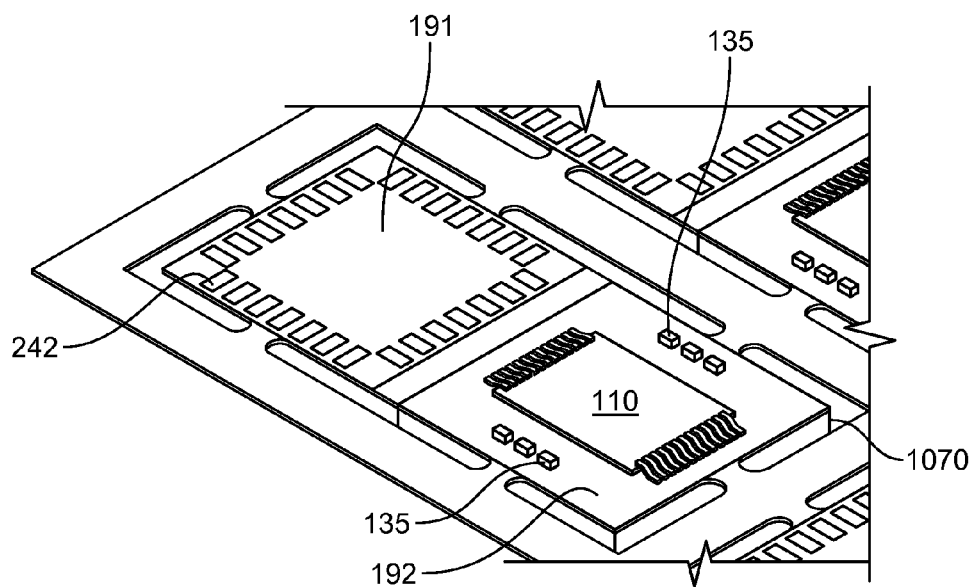


FIG. 10D

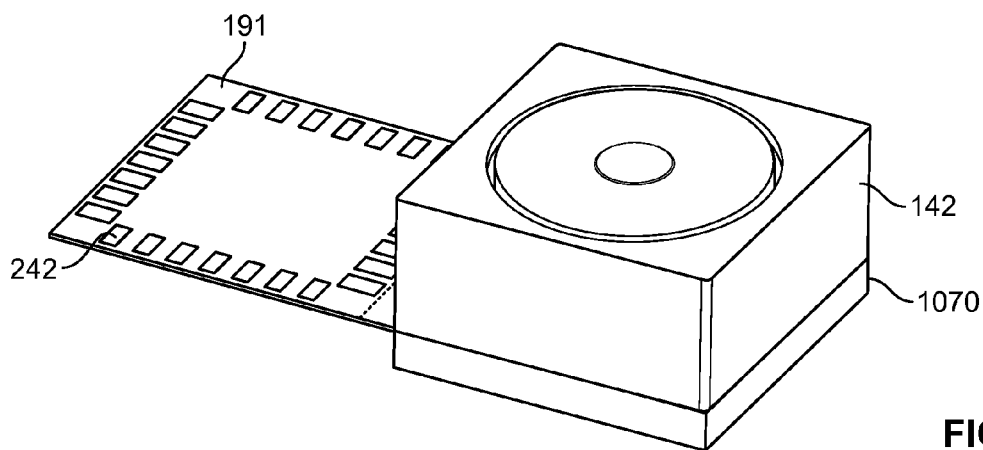


FIG. 10E

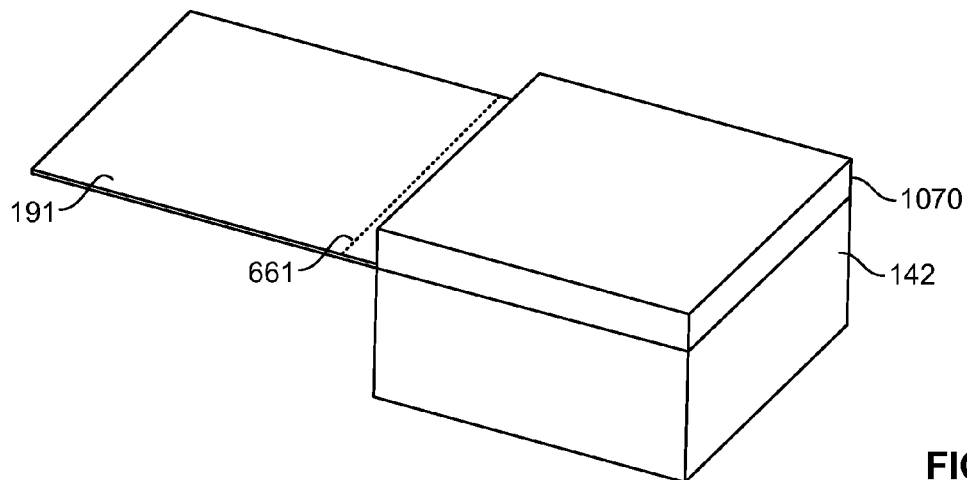


FIG. 10F

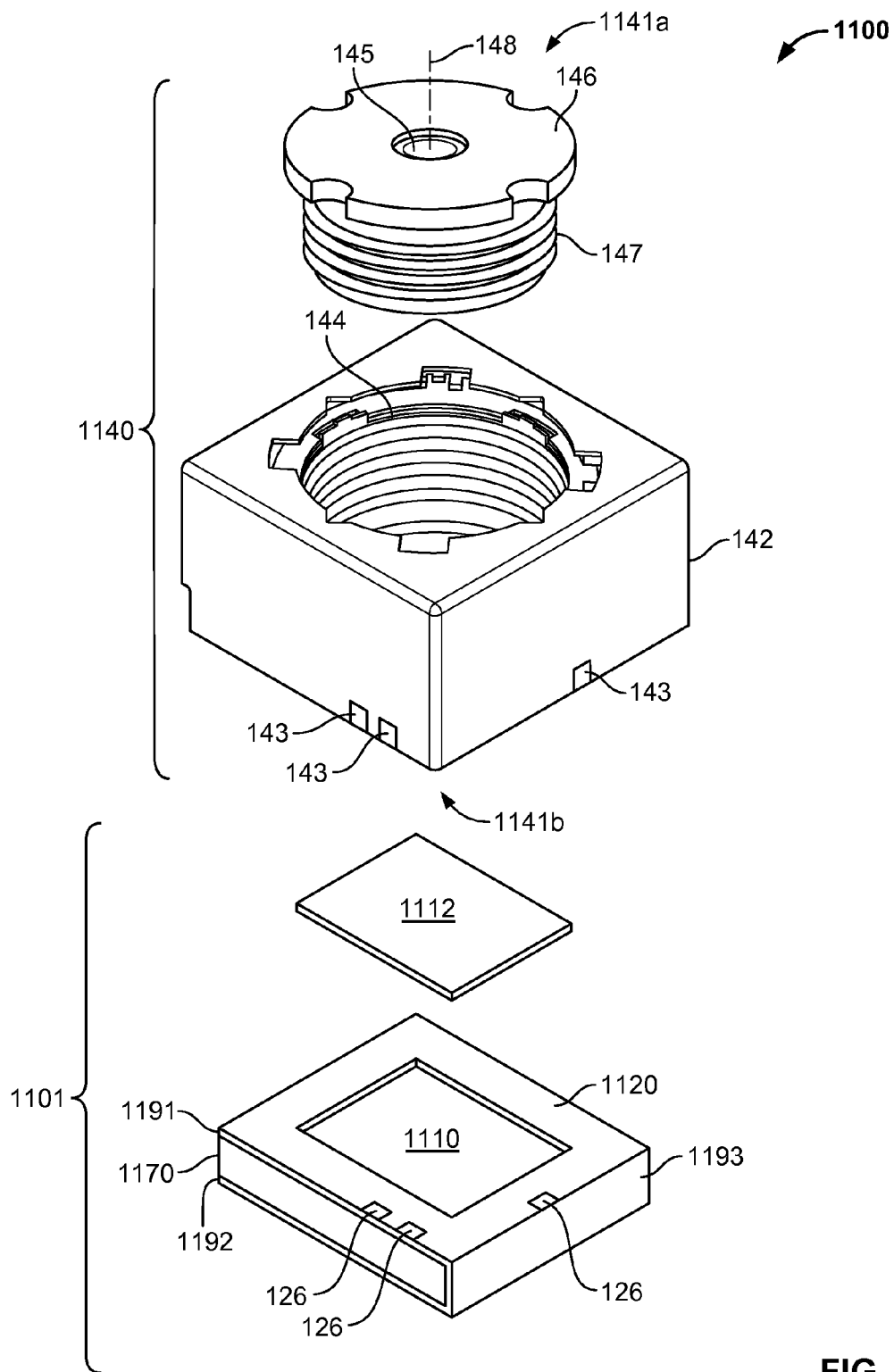


FIG. 11

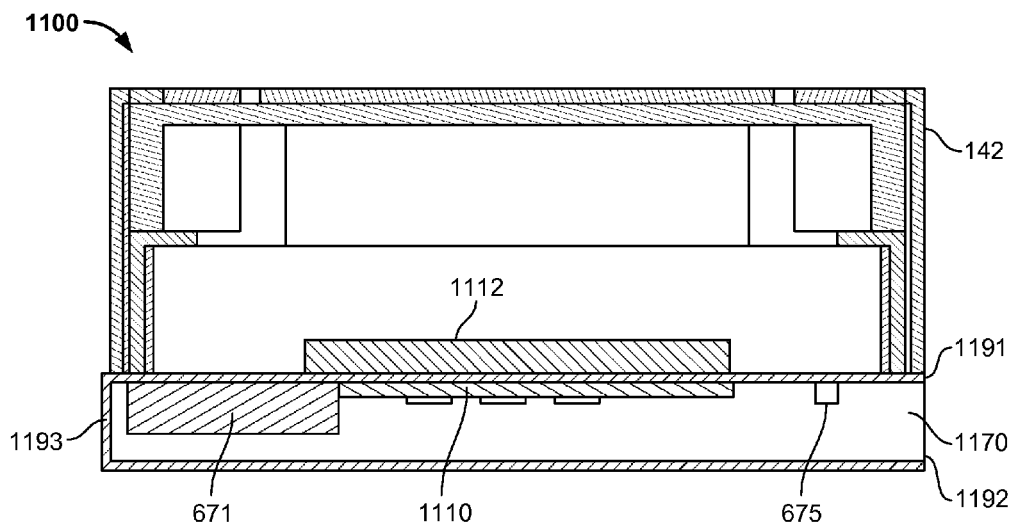


FIG. 12

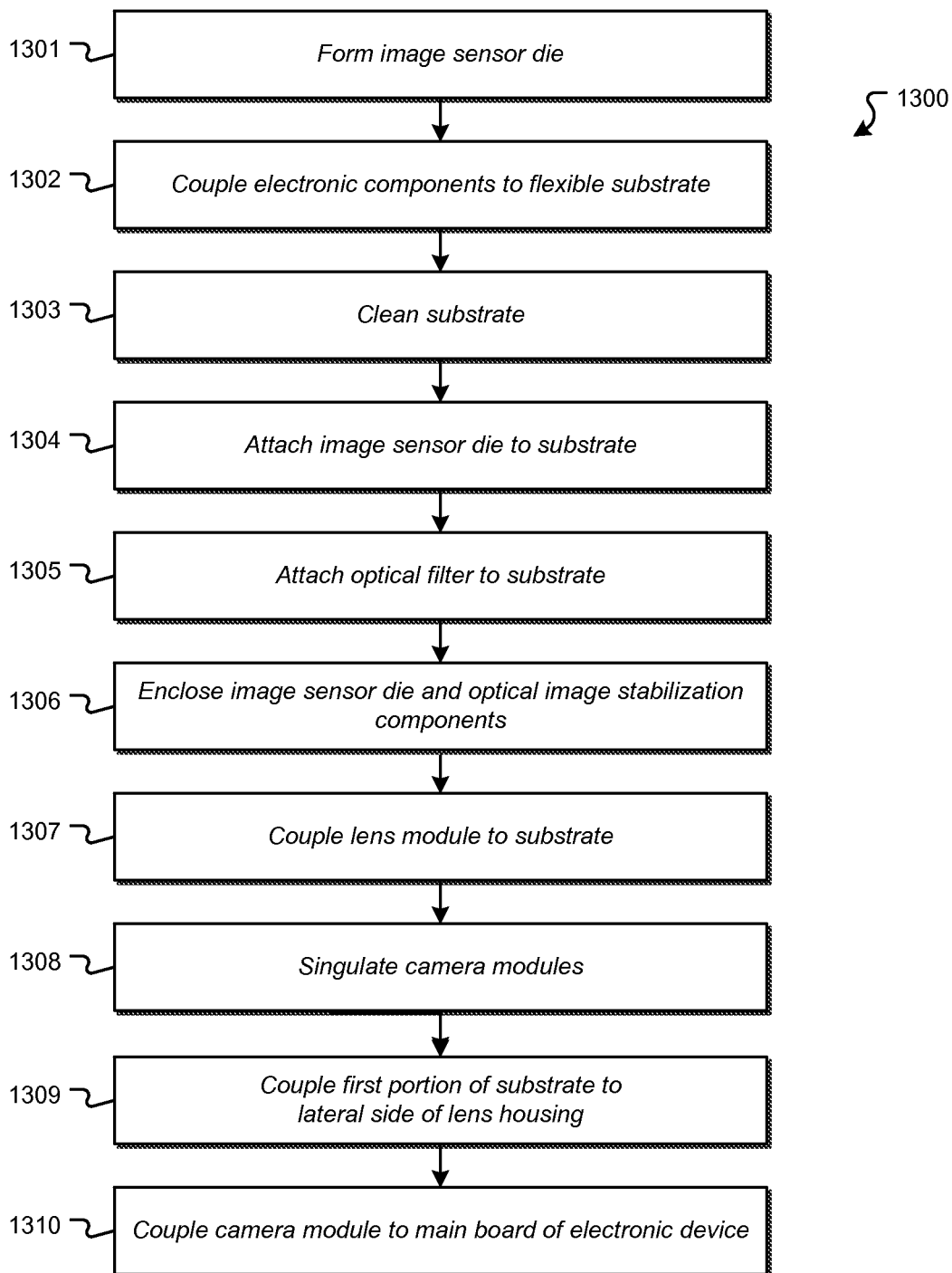


FIG. 13

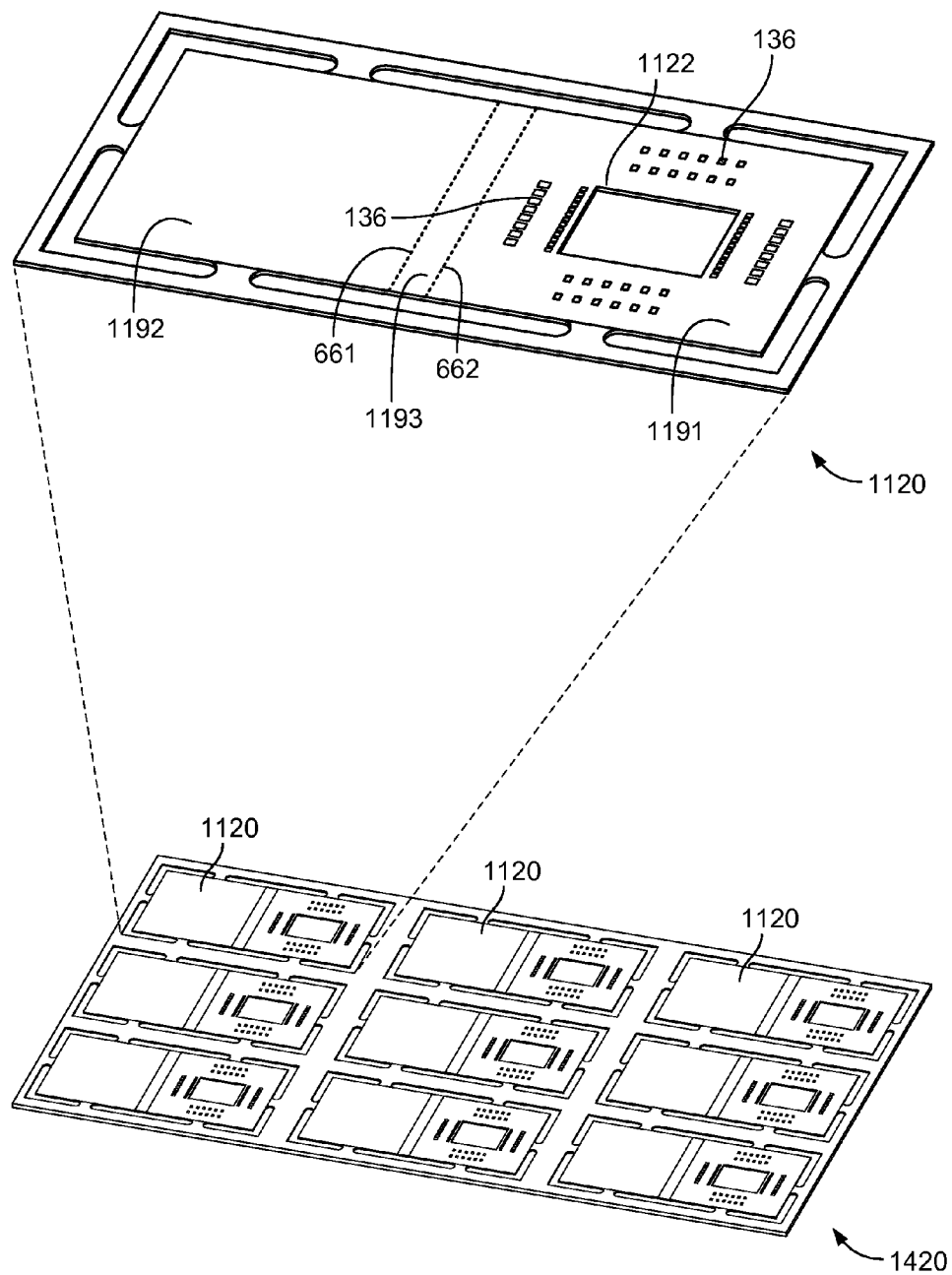


FIG. 14A

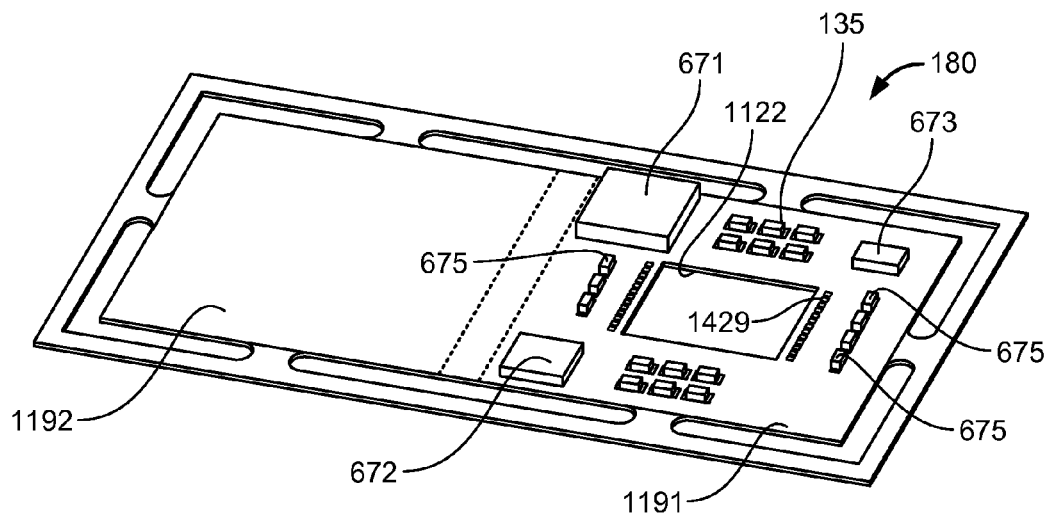


FIG. 14B

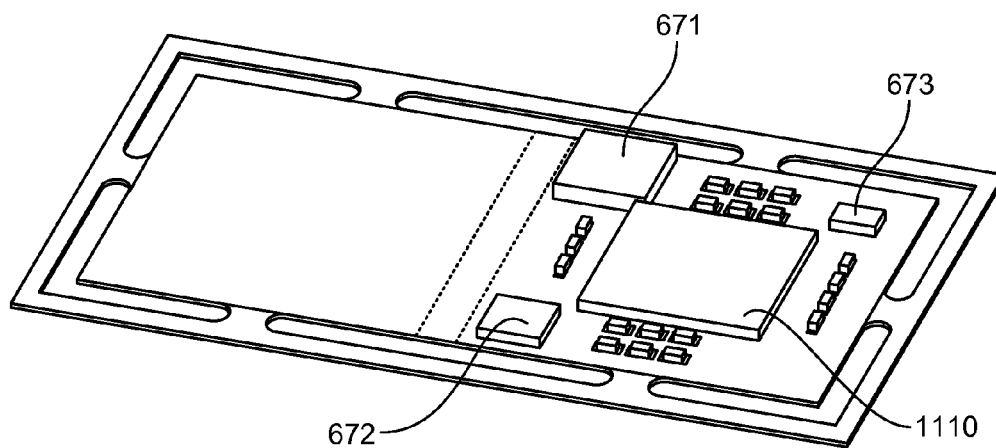


FIG. 14C

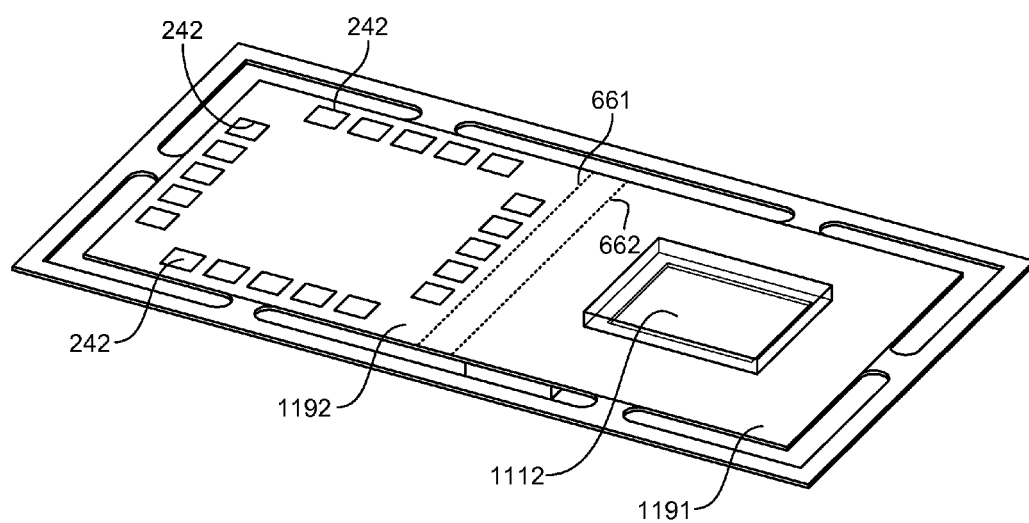


FIG. 14D

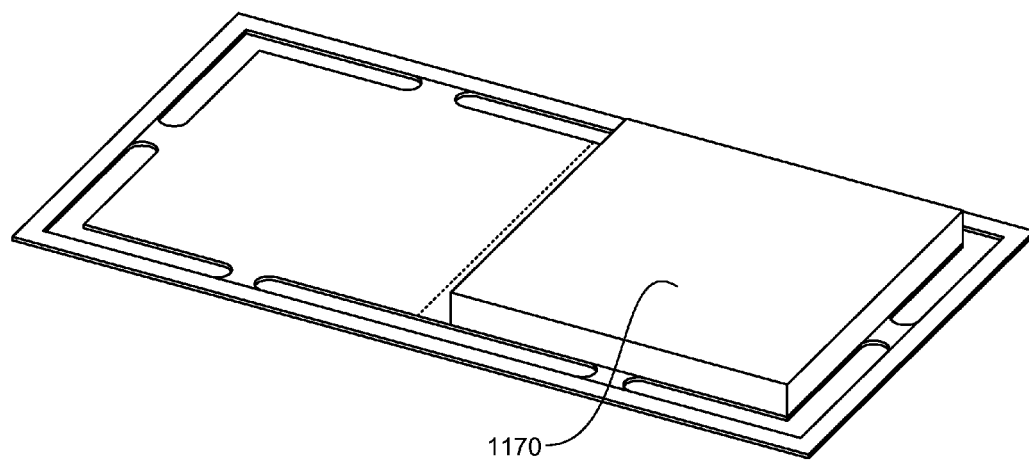


FIG. 14E

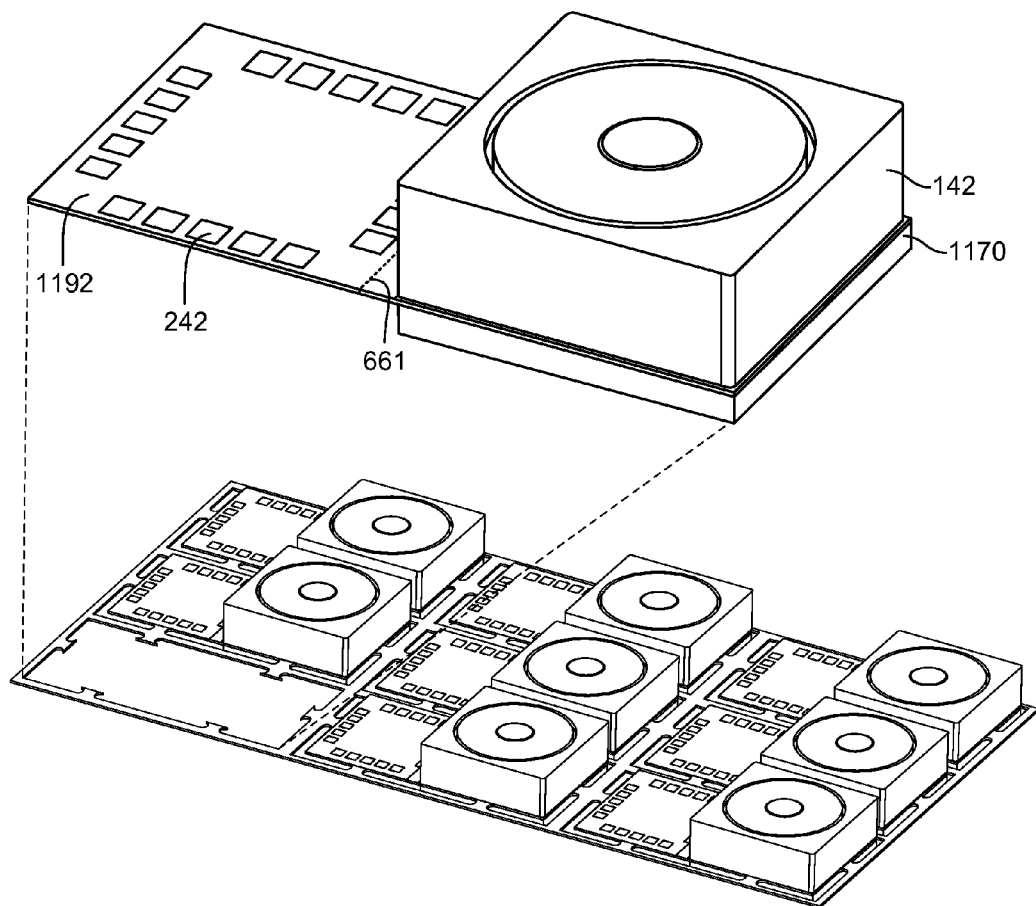


FIG. 14F

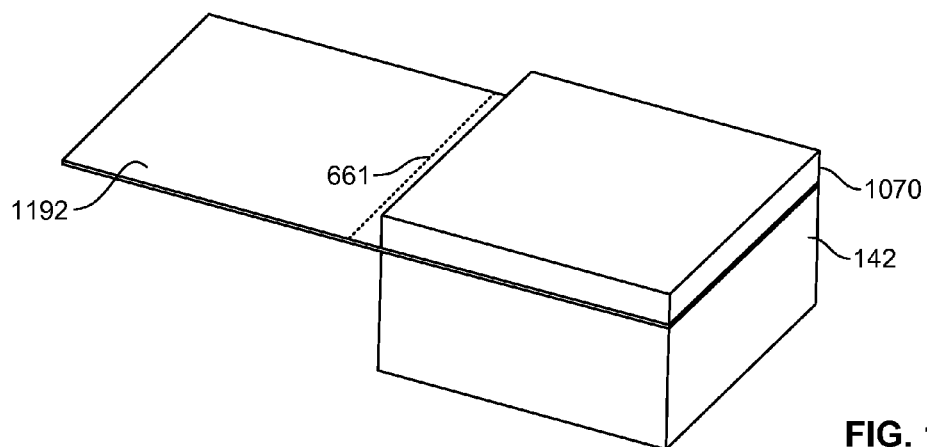


FIG. 14G

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CAMERA MODULE WITH A MOLDED ENCLOSURE CONTAINED IN A FLEXIBLE SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/872,475, filed Aug. 30, 2013, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

Digital camera functionality is being incorporated into a wide variety of electronic devices. In particular, there is an increased demand by consumers for high quality photographic capability in consumer electronics and mobile computing devices, such as mobile phones, smartphones, and tablet computers. However, there is also high demand for mobile computing devices with increasingly small form factors, with extremely thin devices being particularly desirable for both aesthetics and portability. In addition, there is an ongoing desire to improve quality and functionality while decreasing the cost of components and manufacturing.

One common problem experienced by photographers is blurry images caused by shaking of the camera during image capture. Image stabilization technology has been developed to reduce the amount of blurring associated with the movement of the camera. One common approach is optical image stabilization, which utilizes gyro-sensors to detect the angular velocity of the camera. The lens or image sensor is moved in response to this detection, to stabilize the recorded image by varying the optical path to the image sensor. Unfortunately, the various components used to perform image stabilization can consume an undesirably large amount of space inside of the electronic device's housing.

Accordingly, there is a need for improved camera module designs and manufacturing processes for incorporation into electronic devices.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an exploded perspective view of a camera module, in accordance with embodiments of the present invention.

FIGS. 2A-2B illustrate front and back views, respectively, of an example portable computing device that may incorporate a camera module in accordance with embodiments of the present invention.

FIG. 3 is an example block diagram illustrating basic components of a computing device, in accordance with embodiments of the present invention.

FIG. 4 is a cross-sectional view of a camera module, in accordance with embodiments of the present invention.

FIG. 5 is a flowchart illustrating a method of manufacturing a camera module with a flexible substrate folded over a molded enclosure, in accordance with embodiments of the present invention.

FIGS. 6A-6G illustrate various steps in the manufacturing process illustrated in FIG. 5.

FIGS. 7A-7B illustrate perspective views of a camera module, in accordance with embodiments of the present invention.

FIG. 8 is a cross-sectional view of a camera module, in accordance with other embodiments of the present invention.

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FIG. 9 is a flowchart illustrating a method of manufacturing a camera module of FIG. 8, in accordance with embodiments of the present invention.

FIGS. 10A-10F illustrate various steps in the manufacturing process illustrated in FIG. 9.

FIG. 11 is an exploded perspective view of a camera module, in accordance with other embodiments of the present invention.

FIG. 12 is a cross-sectional view of the camera module in FIG. 11, in accordance with embodiments of the present invention.

FIG. 13 is a flowchart illustrating a method of manufacturing a camera module of FIG. 12, in accordance with embodiments of the present invention.

FIGS. 14A-14G illustrate various steps in the manufacturing process illustrated in FIG. 13.

DETAILED DESCRIPTION

In the following description, reference is made to the accompanying drawings which illustrate several embodiments of the present invention. It is understood that other embodiments may be utilized and mechanical, compositional, structural, electrical, and operational changes may be made without departing from the spirit and scope of the present disclosure. The following detailed description is not to be taken in a limiting sense, and the scope of the embodiments of the present invention is defined only by the claims of the issued patent.

Systems and methods in accordance with various embodiments of the present disclosure provide improved manufacturing methods and camera module designs that are compact, inexpensive to manufacture, and reliable in operation. These designs may provide small form factor autofocus (AF) camera modules for incorporation into thin mobile devices, such as tablets or smartphones. In accordance with some embodiments, a camera module includes a flexible substrate wrapped around a molded enclosure. The optical image stabilization components for the camera module may be encapsulated within the molded enclosure. The resulting camera module can achieve a compact footprint with low manufacturing costs.

FIG. 1 is an exploded perspective view of a camera module 100 with a flexible substrate wrapped around a molded enclosure, in accordance with embodiments of the present invention. FIG. 4 is a cross-sectional view of the camera module 100.

The camera module 100 comprises an image sensor module 101 and a lens module 140. The image sensor module 101 comprises an image sensor die 110, an optical filter (not shown), a substrate 120, and electronic components 135.

The lens module 140 comprises an autofocus lens housing 142 forming a cavity containing one or more lenses 145 which are supported by a lens barrel 146. The lens barrel 146 includes a threaded section 147 and is received in a corresponding lens barrel 144, which is driven by motors or actuators in the lens housing 120 to rotate, thereby translating the lens barrel 146 up and down along optical axis 148. The lens module 140 may utilize voice coil motors (VCM) to move the lens barrel 146 along the optical axis 148 of the camera. The VCM may also drive lateral movement of the lens barrel 146 orthogonal to the optical axis 148 in order to provide optical image stabilization to compensate for shaking or other movement of the camera. Alternatively, microelectromechanical systems (MEMS) actuators may be used to translate the lenses 145. A variety of camera modules, including a variety of multi-lens autofocus camera modules, are commercially

available and may be utilized in accordance with various embodiments of the present invention.

The lens module **140** comprises an image receiving side **141a** and an image sensor side **141b**. The image receiving side **141a** faces the object being photographed when the camera module **100** is in use. The image sensor side **141b** faces the image sensor die **110**.

The substrate **120** may comprise any form of circuit substrate suitable to provide the necessary interconnection structure for operation of the camera module **100**, as is well known in the art. The substrate **120** may comprise, for example, a flexible substrate, such as a flexible high density interconnect (HDI) tape substrate, which is available in very thin configurations. The HDI tape substrate may comprise a multilayer interconnect structure using polyimide as a dielectric and electroplated copper conductor lines. The flexible substrate **120** may comprise a flexible base material comprising, e.g., polyester, polyimide, polyethylene naphthalate, or polyetherimide, and conductive layers comprising, e.g., conductive metal foil, electroplated copper, screen printing metal circuits, or other conductive materials. Alternatively, the flexible substrate **120** may comprise a rigid flex substrate having one or more interconnect and dielectric layers.

The flexible substrate **120** may comprise a single body that extends over the top and bottom sides of an enclosure **170** and comprises a first portion **191** which is positioned on top of the enclosure **170** adjacent to the image sensor side **141b** of the lens module **140**, a second portion **192** which is positioned on the bottom of the enclosure **170** opposite the first portion **191**, and a third portion **193** which is positioned on the side of the enclosure **170** to couple the first portion **191** and the second portion **192**.

The first portion **191** includes a plurality of substrate-sensor contacts **129**. The image sensor die **110** includes a plurality of output die contacts **111** formed along one or more edges of the image sensor die **110**. The output die contacts **111** are coupled to the substrate-sensor contacts **129**, as will be described in greater detail below.

In the illustrated embodiment, the first portion **191** of the substrate **120** includes a plurality of component contacts **134** for coupling with the electronic components **135**. The electronic components **135** may include passive and/or active components for processing the output signals from the image sensor. The passive components may include inductors, capacitors, or resistors. The electronic components **135** are coupled to the component contacts **134** formed on the substrate **120**, thereby electrically coupling the passive components **135** with the image sensor die **110** via the substrate-sensor contacts **129**.

The second portion **192** of the substrate **120** includes a second plurality of component contacts **136** for coupling with the image stabilization components **180** (not shown in FIG. 1), as will be described in greater detail below.

The second portion **192** of the flexible substrate **120** further includes a main board contact region **244** (shown in FIG. 4). The main board contact region **244** includes a plurality of LGA pads **242** which may be coupled to main board contacts on the main board of the electronic device. The LGA pads **242** receive all of the power and I/O signals required for operation of the camera module **100**. The LGA pads **242** can be bonded (e.g., soldered) directly to corresponding contacts on the main board, coupled to an LGA socket mounted to the main board, or coupled to another intermediate interposer structure, such as a cable or circuit board, which is coupled to the main board.

The image sensor die **110** includes a photosensor portion **113** comprising any type of image capturing element that converts an optical image into an electronic signal, such as,

e.g., a charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) active pixel sensor.

An optical filter (not shown) may be used to improve the quality of the images generated by the camera module. The optical filter may be used for filtering undesirable wavelengths of light, such as infrared light, received by the lens module **140** to prevent the light from reaching the photosensor portion **113** of the image sensor die **110**, which could degrade the quality of digital image generated. In other embodiments, other types of optical filters may be used, such as, for example, a blue or other color filter, or a polarizing filter. The optical filter may be positioned in a variety of locations within the camera module **100**. For instance, a spacer member may be coupled to the upper side **121a** of the flexible substrate **120** around the image sensor die **110**. The spacer member may be used to support the optical filter above the image sensor die **110** and bond wires **128** coupling the image sensor die **110** to the flexible substrate **120**. In other embodiments, the optical filter may be coupled to the lens housing **142**.

The camera module **100** may be incorporated into any of a variety of electronic devices. FIGS. 2A-2B illustrate front and back views, respectively, of an example portable computing device **200** that may incorporate a camera module in accordance with various embodiments described herein. Although one example of an electronic device is shown, it should be understood that various other types of electronic devices that are capable of incorporating digital camera functionality can be used in accordance with various embodiments discussed herein. The electronic devices can include, for example, smartphones, electronic book readers, tablet computers, notebook computers, personal data assistants, cellular phones, video gaming consoles or controllers, television set top boxes, and portable media players, among others.

In this example, the portable computing device **200** has a display **202** (e.g., a liquid crystal display (LCD) element) operable to display image content to one or more users or viewers of the device. In at least some embodiments, the display screen provides for touch or swipe-based input using, for example, capacitive or resistive touch technology.

FIG. 3 is an example block diagram illustrating basic components of a computing device, such as computing device **200**. In this example, the device **200** includes at least one processor **202** for executing instructions that can be stored in at least one memory device **204**. As would be apparent to one of ordinary skill in the art, the memory device **204** can include one or more different types of memory, data storage or computer-readable storage media, such as, for example, a first data storage for program instructions for execution by the processor **202**, a second data storage for images or data and/or a removable storage for transferring data to other devices.

The computing device **200** includes one or more camera modules **100** configured to capture an image of people or objects in the vicinity of the device **200**. The computing device **200** may include a main board, which may be the primary circuit board for the computing device **200** onto which one or more of the following components may be mounted. The camera module **100** includes a circuit substrate **120** which may be electrically coupled to the main board of the computing device **200** in a variety of ways, such as by direct mounting to the main board or with an interposer, which serves as an intermediate coupling device providing an electrical interface between the circuit substrate **120** and the main board. The interposer may comprise, for example, a cable or a rigid or flexible circuit board having interfaces coupled to the circuit substrate **120** and the main board, as will be described in greater detail below.

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The computing device **200** includes a display element **206** for displaying images using technologies such as, for example, electronic ink (e-ink), organic light emitting diode (OLED) or liquid crystal display (LCD). The computing device **200** may also include an audio element **210**, such as one or more audio speakers **211** and/or audio capture elements capable of capturing audio data, such as microphones **213**. The computing device **100** may also include a positioning element **212**, such as motion, position or orientation determining element **215**, that provides information such as a position, direction, motion, or orientation of the device **200**. The computing device **200** can include one or more input elements **218** operable to receive inputs from a user. The input elements **218** can include, for example, a push button, touch pad, touch screen, wheel, joystick, keyboard, mouse, trackball, keypad or any other such device or element whereby a user can provide inputs to the computing device **200**. The computing device **200** may also include at least one communication interface **214**, comprising one or more wireless components operable to communicate with one or more separate devices within a communication range of the particular wireless protocol. The wireless protocol can be any appropriate protocol used to enable devices to communicate wirelessly, such as Bluetooth, cellular, or IEEE 802.11. It should be understood that the computing device **200** may also include one or more wired communications interfaces for coupling and communicating with other devices. The computing device **200** may also include a power supply **216**, such as, for example, a rechargeable battery operable to be recharged through conventional plug-in approaches, or through other approaches such as capacitive charging.

FIG. 5 is a flowchart illustrating a method **500** of manufacturing a camera module **100** with a flexible substrate folded over a molded enclosure, in accordance with embodiments of the present invention. FIGS. 6A-6G illustrate various steps in the manufacturing method **500**.

In step **501**, shown in FIG. 6A, the image sensor die **110** is formed. Before each image sensor die **110** is singulated or diced from the wafer **600** held in the wafer carrier **602**, a plurality of die contacts **111** are formed on the upper surface **601a** of each image sensor die **110**. The die contacts **111** can be formed in a variety of ways, depending on the desired method of coupling the image sensor die **110** to the substrate **120**. In some embodiments, the die contacts **111** on the image sensor die **110** may be used for wire bonding with the substrate **120**. The die contacts **111** may be formed using any of a variety of well-known techniques, such as, for example, using ball bonds. In other embodiments, the die contacts **111** on the image sensor die **110** may be used for flip chip bonding with the substrate **120**, in which case, the die contacts **111** may comprise gold stud bumps. Alternatively, the die contacts **111** may comprise any other type of suitable material and form, such as, e.g., sputter plated bumps, gold plated bumps, or copper pillar bumps.

In step **502**, shown in FIGS. 6B-6C, a plurality of substrates **120** are provided in a substrate strip array **620** and electronic components are coupled to the second portion **192** of the substrate **120**.

FIG. 6B is a perspective view of the interior side of the substrate **120**. As will be described in greater detail below, the substrate **120** will be folded to wrap around the enclosure **170**. The interior side of the substrate **120** will face the enclosure **170** and the exterior side (shown in FIG. 6E) will be exposed for coupling with the lens module **140** and the main board of the electronic device into which the camera module **100** is integrated.

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Fold lines **661**, **662** are shown for illustrative purposes to indicate where the substrate **120** will be folded when coupled to the enclosure **170**. In some embodiments, fold lines **661**, **662** correspond to mechanical features in the substrate **120** for facilitating the folding of the substrate **120**, such as a scoring line. In other embodiments, the fold lines **661**, **662** do not represent any physical features and are merely illustrative of the location of a later folding step.

As shown in FIG. 6B, the interior side of each substrate **120** includes a plurality of component contacts **136**. Electronic components (shown in FIG. 6C) may be coupled to each of these contacts **136** using, e.g., surface mount technology (SMT). The various contacts provided on the substrate **120** may be formed, e.g., using electroless nickel immersion gold (ENIG) plating techniques. ENIG is an electroless nickel layer capped with a thin layer of immersion gold, which provides a multifunctional surface finish. The immersion gold protects the underlying nickel from oxidation/passivation.

The electronic components mounted to the second portion **192** of the substrate **120** may comprise image stabilization components **180** used to provide an optical image stabilization (OIS) functionality for the camera module **100**. These image stabilization components **180** may comprise, for example, a gyroscopic sensor **671**, a memory **672**, an optical image stabilization logic module **673**, and passive electronic components **675**. The gyroscopic sensor **671** may comprise one or more sensors for sensing movement along one or more axes. In some embodiments, the gyroscopic sensor **671** may sense movement along two axes, thereby enabling correction for pitch and yaw axis rotations. The memory **672** may comprise a non-volatile EPROM memory for storing the firmware instructions for the operation of the OIS functionality. The optical image stabilization logic module **673** may comprise a controller with logic for executing the OIS functionality. The image stabilization components **180** may be mounted to the substrate **120** using any suitable manufacturing technique, such as the SMT mounting process described above.

In step **503**, shown in FIG. 6D, the image stabilization components **180** are encapsulated in an enclosure **170**. In some embodiments, the enclosure **170** comprises any of a variety of transfer molding materials well-known in the semiconductor packaging industry. The transfer molding material may comprise a resin with a hardener, accelerator, fillers, flame retardants, and other modifiers, such as an epoxy resin with a silica filler. In the illustrated embodiment, the molded enclosure **170** serves to protect the image stabilization components **180** and to provide a flat surface for bonding with the first portion **191** of the substrate **120**. The transfer molding material can be advantageous in this application because its manufacturing processes are well known and relatively inexpensive, and its physical characteristics are well documented. In other embodiments, the enclosure **170** may comprise another material. A rigid enclosure **170** comprising, e.g., a metal or polymer, may be formed prior to attachment to the substrate **120**, and may be attached to the substrate **120** to enclose the image stabilization components **180**. In some embodiments, a grounded metal enclosure **170** may advantageously provide RF shielding and isolation for the electronic components contained therein.

In step **504**, shown in FIG. 6E, additional electronic components **135** are coupled to the first portion **191** of the substrate **120** using, e.g., SMT processes. FIG. 6E shows a perspective view of the exterior side of the substrate **120**. The exterior side of the first portion **191** of the substrate **120** includes a plurality of component contacts **134** for coupling with additional components **135**. In accordance with some

embodiments of the present invention, the electronic components **135** on the first portion **191** of the substrate **120** comprise decoupling capacitors that are coupled to the substrate **120** along the two sides of the image sensor die **110** not used for wire bonding of the die **110** to the substrate **120**. As a result, the decoupling capacitor passive components **135** may be placed as close as possible to the image sensor die **110**, thereby improving the image signal from the die **110**. Other passive components **675** that do not require close proximity to the image sensor die **110** or that require close proximity to the other image stabilization components **180**, such as the gyroscopic sensor **671** and optical image stabilization logic module **673**, may be coupled to the second portion **192** of the substrate **120**.

In step **505**, shown in FIG. **6E**, the image sensor die **110** is attached to the exterior side of the first portion **191** of the substrate **120**, using, for example, an epoxy adhesive, and the die contacts **111** on the upper surface of each image sensor die **110** are wire bonded to substrate-sensor contacts **129** on the upper surface of the flexible substrate **120**. Each of the die contacts **111** is coupled to a respective one of the substrate-sensor contacts **129** using a bond wire **128**, e.g., a gold bond wire, which extends across the gap separating the flexible substrate **120** and the image sensor die **110**.

In step **506**, shown in FIG. **6F**, a lens housing **142** is coupled to the exterior side of the first portion **191** of each of the substrate assemblies **120** in the substrate strip array **620**. The lens housing **142** may be attached to the substrate **120** by depositing an adhesive, such as an epoxy adhesive, onto a portion of the substrate **120** not otherwise used for electrical connections. The lens module connections **126** (shown in FIG. **6E**) on the substrate **120** may then be coupled to the corresponding contacts **143** in the lens housing **142** using, for example, conventional soldering methods. These lens module connections **126** may be used to provide power, ground, and control signals to the lens module **140**.

In step **507**, each camera module **100** may then be singulated from the strip array **620**. In some embodiments, the substrate assemblies **120** may be singulated from the strip array **620** prior to attachment of the lens housings **142**. However, in other embodiments, it is desirable to attach the lens housings **142** to each of the substrates **120** prior to singulation from the array **620**. This bulk processing can result in an improvement in the manufacturing units per hour (UPH). In addition, after the lens housings **142** are attached, the strip array **620** may be coupled to a test fixture which establishes electrical connections with each of the camera modules **100** in the array **620**. This can enable the test fixture to power up and test each of the camera modules **100** prior to singulation. During this testing, an active alignment process may be performed to ensure that the optical path through the lenses **145** is accurately aligned with the image sensor die **110**. The active alignment process can measure the optical characteristics of the lenses **145** and image sensor die **110** and adjust the alignment in up to five degrees of freedom. By attaching the lens housing **142** and performing the active alignment process prior to singulation, the testing and alignment can be performed in a batch process, thereby improving UPH.

In step **508**, the interior side of the first portion **191** of the substrate **120** is coupled with the molded enclosure **170**. This can be accomplished by depositing an adhesive to either or both the enclosure **170** and the interior side of the substrate **120**, as shown in FIG. **6G**. Next, the substrate **120** is folded along fold lines **661**, **662** to press the enclosure **170** against the interior side of the first portion **191** of the substrate, as shown in FIG. **7A**. Any of a variety of known adhesives may be used to couple the enclosure **170** to the substrate **120**. In

some embodiments, the lens housing **140** may comprise stainless steel, in which case an adhesive suitable for bonding a transfer mold compound with the substrate material of the substrate **120**, such as, for example, solder.

FIGS. **7A-7B** show top and bottom perspective views, respectively, of the completed camera module **100**. As shown in FIG. **7B**, the interior side of the second portion **192** of the substrate **120** is exposed on the bottom of the camera module **100**. This exposed portion of the substrate **120** includes a main board contact region **244** comprising a plurality of main board contacts **242**, e.g., LGA pads **242**. When the camera module **100** is integrated into an electronic device, such as computing device **200**, the LGA pads **242** may be coupled to main board contacts on the main board of the electronic device.

In step **509**, the camera module **100** is coupled to the main board of the electronic device to form a completed camera assembly. This may be accomplished using any of a variety of known methods. In the illustrated embodiment, the LGA pads **242** are provided along a peripheral edge of the exterior side of the second portion **192** of the substrate **120**. This arrangement can improve the manufacturability of the camera module **100** by permitting easy access to the LGA pads **242** for reworking if one of the soldering bonds between the PGA pads **242** and the main board contacts fails.

FIG. **8** is a cross-sectional view of a camera module **800**, in accordance with other embodiments of the present invention. The camera module **800** is similar to the camera module **100** described above, except that the image stabilization components are coupled to the interior side of the first portion of the substrate **820**, instead of to the second portion of the substrate **120**, as in camera module **100**.

FIG. **9** is a flowchart illustrating a method **900** of manufacturing the camera module **800** with a flexible substrate folded over a molded enclosure, in accordance with embodiments of the present invention. FIGS. **10A-10G** illustrate various steps in the manufacturing method **900**.

In step **901**, the image sensor die **110** is formed.

In step **902**, shown in FIGS. **10A-10B**, a plurality of substrates **820** are provided in a substrate strip array **1020** and electronic components are coupled to the interior side of the first portion **1091** of the substrate **820**. FIG. **10A** is a perspective view of the interior side of the substrate **820** before the components are attached, and FIG. **10B** is a perspective view of the interior side of the substrate **820** after the components are attached.

As shown in FIG. **10A**, the interior side of each substrate **820** includes a plurality of component contacts **136**. However, unlike the contacts **136** in the substrate **120** shown in FIG. **6B**, the contacts **136** in FIG. **10A** are formed on the first portion **1091** of the substrate **820**. The electronic components mounted to the first portion **191** of the substrate **820** may comprise image stabilization components **180**, similar to those described above with respect to FIG. **6C**.

In step **903**, shown in FIG. **10C**, the image stabilization components **180** are encapsulated in an enclosure **1070**. The enclosure **1070** is similar to the enclosure **170** described above, except that it is formed on the first portion **1091** of the substrate **820**.

In step **904**, additional electronic components **135** are coupled to the exterior side of the first portion **1091** of the substrate **820**. FIG. **10D** shows a perspective view of the exterior side of the substrate **820**.

In step **905**, shown in FIG. **10D**, the image sensor die **110** is coupled to the exterior side of the first portion **1091** of the substrate **820** and the die contacts **111** on the upper surface of

each image sensor die **110** are wire bonded to substrate-sensor contacts **129** on the upper surface of the substrate **820**.

In step **906**, shown in FIG. **10E**, the lens housing **142** is coupled to the exterior side of the first portion **1091** of each of the substrate assemblies **820** in the substrate strip array **1020**.

In step **907**, each camera module **800** is singulated from the strip array **1020** for integration with an electronic device, such as computing device **200**.

In step **908**, the interior side of the second portion **1092** of the substrate **820** is coupled with the molded enclosure **1070**. This can be accomplished by depositing an adhesive to either or both the enclosure **1070** and the interior side of the substrate **820**, as shown in FIG. **10G**. Next, the substrate **820** is folded along fold lines **661**, **662** to adhere the enclosure **1070** against the interior side of the first portion **1091** of the substrate, resulting in a camera module **800**, similar in exterior appearance to the camera module **100** shown in FIG. **7A**.

In step **909**, the camera module **800** is coupled to the main board of the electronic device to form a completed camera assembly.

FIG. **11** is an exploded perspective view of a camera module **1100** with a flexible substrate folded over a molded enclosure and a flip chip mounted image sensor die, in accordance with embodiments of the present invention. FIG. **12** is a cross-sectional view of the camera module **1100**.

The camera module **1100** comprises a lens module **1140** and image sensor module **1101**. The lens module **1140** is similar to the lens module **140** described above and comprises an autofocus lens housing **142** forming a cavity containing one or more lenses.

The image sensor module **1101** comprises an optical filter **1112** and a substrate **1120** which extends over the top and bottom sides of an enclosure **1170**. The substrate **1120** comprises a first portion **1191** which is positioned on top of the enclosure **1170** adjacent to the image sensor side **1141b** of the lens module **140**, and a second portion **1192** which is positioned on the bottom of the enclosure **1170** opposite the first portion **1191**. The substrate **1120** also includes an image sensor opening **1122**, which exposes the image sensor die **1110** to the light received by the lenses **145**. The substrate **1120** may comprise any form of circuit substrate suitable to provide the necessary interconnection structure for operation of the camera module **1100**, as described above.

FIG. **13** is a flowchart illustrating a method **1300** of manufacturing a camera module **100** with a flexible substrate folded over a molded enclosure, in accordance with embodiments of the present invention. FIGS. **14A-14F** illustrate various steps in the manufacturing method **1300**.

In step **1301**, the image sensor die **1110** is formed. In the illustrated embodiment, the image sensor die **1110** is flip chip bonded to the substrate **1120**. Accordingly, the die contacts on the image sensor die **1110** may comprise gold stud bumps, or any other type of suitable material and form, such as, e.g., sputter plated bumps, gold plated bumps, or copper pillar bumps.

FIG. **14A** is a perspective view of the interior side of the substrate **1120**. As with embodiments described above, the substrate **1120** will be folded to wrap around the enclosure **1170** such that the interior side of the substrate **1120** will face the enclosure **1170** and the exterior side will be exposed for coupling with the lens module **1140** and the main board of the electronic device into which the camera module **1100** is integrated.

In step **1302**, shown in FIGS. **14A-14B**, a plurality of substrates **1120** are provided in a substrate strip array **1420** and components are coupled to the substrate **1120**. As shown in FIG. **14A**, the interior side of the first portion **1191** of each

substrate **1120** includes a plurality of component contacts **136** positioned around one or more sides of the image sensor opening **1122**. Electronic components may be coupled to each of these contacts **136** using, e.g., surface mount technology (SMT), as described above.

The components mounted to the first portion **1191** of the substrate **1120** may comprise image stabilization components **180** and passive electronic components **135**, as described above. In this embodiment, the electronic components **135** may include decoupling capacitors for the image sensor die **1110** positioned close to the edges of the die **1110** that are not used for wire bonding. Other components not requiring close proximity to the die **1110** may be positioned along the edges of the die **1110** that are used for wire bonding or in the corners of the first portion **1191** of the substrate **1120**.

In step **1303**, the substrate **1120** is cleaned to remove impurities or other contaminants that may have been deposited onto the substrate **1120** in previous steps.

In step **1304**, the image sensor die **1110** is attached to the substrate **1120**. The bonding of the image sensor die **1110** to the substrate **1120** may be performed in a variety of ways. In the embodiment illustrated in FIG. **11C**, flip chip bonding is used to bond gold stud bump die contacts on the die **1110** with substrate-sensor land pad contacts **1429** (shown in FIG. **14B**).

In one embodiment, flip chip bonding using a conductive epoxy process followed by a jetting underfill process may be used. In another embodiment, flip chip bonding using a thermal ultrasonic (T/S) bonding process to form an inter-metallic coverage (IMC) between the die contacts and substrate-sensor contacts **1429** followed by a jetting underfill process may be used. In another embodiment, flip chip bonding using a thermal-compression (T/C) bonding process with a non-conductive paste (NCP) dispensed on the substrate-sensor contacts **1429** may be used. In another embodiment, flip chip bonding of plated bump die contacts using a T/C bonding process with an anisotropic conductive paste (ACP) dispensed on the substrate-sensor contacts **1429** may be used.

In step **1305**, shown in FIG. **14D**, the optical filter **1112** is coupled to the exterior side of the first portion **1191** of the substrate **1120**. The optical filter **1112** can be any type of filter desired for the camera module **1100**, similar to the optical filter **112** described above. The optical filter **1112** is bonded to the exterior side of the first portion **1191** around the image sensor opening **1122**, thereby providing a protective seal to prevent contaminants and other debris from contacting the photosensor portion of the image sensor die **1110**. This protection is particularly advantageous when the substrate **1120** is exposed to high levels of contaminants, as occurs during the transfer molding process described below. In some embodiments, the optical filter **1112** may be attached to the substrate **1120** prior to the flip chip mounting of the image sensor die **1110** to the substrate **1120**.

In step **1306**, shown in FIG. **14E**, the enclosure **1170** is coupled to the interior side of the first portion **1191** of the substrate **1120**. The various devices coupled to the interior side of the first portion **1191** of the substrate **1120**, including the image sensor die **1110** and the image stabilization components **180**, are encapsulated in the enclosure **1170**. In some embodiments, the enclosure **1170** comprises a transfer molded enclosure, as described above with respect to the enclosure **170**. In the illustrated embodiment, the molded enclosure **1170** serves to protect the image stabilization components **180** and to provide a flat surface for bonding with the second portion **1192** of the substrate **1120**. In other embodiments, the enclosure **1170** may comprise another material, such as a rigid enclosure comprising, e.g., a metal or polymer, formed prior to attachment to the substrate **1120**, and attached

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to the substrate **1120** to enclose the image stabilization components **180** and image sensor die **1110**.

In step **1307**, shown in FIG. **14F**, a lens module **1140** is coupled to each of the substrates **1120** in the substrate strip array **1420**.

In step **1308**, each camera module **1100** may then be singulated from the strip array **1420** for integration with an electronic device. As described above, in some embodiments it may be desirable to couple the lens module **1140** to the substrate **1120** prior to singulation so that the batch test and active alignment process can be performed. In other embodiments, the substrates **1120** may be singulated prior to attaching the lens modules **1140**.

In step **1309**, the interior side of the second portion **1192** of the substrate **1120** is coupled with the molded enclosure **1170**. This can be accomplished by depositing an adhesive to either or both the enclosure **1170** and the interior side of the substrate **1120**, as shown in FIG. **14G**. Next, the substrate **1120** is folded along fold lines **661**, **662** to press the enclosure **1170** so as to adhere the enclosure **1170** to the interior side of the first portion **1191** of the substrate **1120**, thereby resulting in the camera module **1100**, similar in exterior appearance to the camera module **100** shown in FIGS. **7A-7B**.

In step **1310**, the camera module **1100** is coupled to the main board of the electronic device to form a completed camera assembly.

The above-described embodiments may achieve a number of advantages over conventional camera module designs. The overall size of the camera module may be reduced and, in particular, the footprint of the camera module may be reduced by positioning the various OIS and other electronic components underneath the lens module rather than on a portion of the substrate extending out from the lens module. In addition, in some embodiments, the molded enclosure is sized so as to have approximately the same length and width of the image sensor side of the lens module. As a result, the camera module is provided with a roughly rectangular form factor. This may improve the ease with which the camera module is handled in later processing steps, such as when coupling the camera module to the main board of the electronic device **200**. In other embodiments, the molded enclosure may have different dimensions from the lens module. This may be desirable if the region of the substrate to be enclosed by the molded enclosure is smaller than the image sensor side of the lens module. In this case, the enclosure may be smaller than the image sensor side, such as, e.g., $\frac{3}{4}$, $\frac{1}{2}$, or $\frac{1}{4}$ of the size of the image sensor side of the lens module. In other embodiments, the enclosure may be larger than the image sensor side of the lens module.

Because HDI tape substrates provide much higher line pitch than conventional laminate substrates, the use of HDI tape substrates can enable a reduction in the number of layers necessary for the interconnect structure of the substrate. Exemplary HDI tape substrates may have, for example, a line pitch of between $16\text{ }\mu\text{m}$ - $50\text{ }\mu\text{m}$.

Flip chip bonding of an image sensor die utilizes the application of pressure and heat to the back side of the die, which requires that the die be thick enough to withstand the pressure without damage. However, when the image sensor die is wire bonded to the substrate assembly, as described in embodiments above, pressure and heat need not be applied to the die, thereby enabling a reduction in die thickness.

In addition, the ability to perform numerous steps in the manufacturing process while the substrate assemblies remain in strip array format can enable more efficient batch processing, thereby reducing the cost per unit. Flexible tape substrates may be provided in even larger strips than conventional ceramic and laminate strip arrays, thereby increasing

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the number of camera modules that may be manufactured in each batch, resulting in an improvement in the manufacturing units per hour (UPH).

Although the flowcharts and methods described herein may describe a specific order of execution, it is understood that the order of execution may differ from that which is described. For example, the order of execution of two or more blocks or steps may be scrambled relative to the order described. Also, two or more blocks or steps may be executed concurrently or with partial concurrence. Further, in some embodiments, one or more of the blocks or steps may be skipped or omitted. It is understood that all such variations are within the scope of the present disclosure.

It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the disclosure. The various features and processes described above may be used independently of one another, or may be combined in various ways. All possible combinations and subcombinations are intended to fall within the scope of this disclosure.

In addition, conditional language, such as, among others, “can,” “could,” “might,” or “may,” unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or steps.

Although this disclosure has been described in terms of certain example embodiments and applications, other embodiments and applications that are apparent to those of ordinary skill in the art, including embodiments and applications that do not provide all of the benefits described herein, are also within the scope of this disclosure. The scope of the inventions is defined only by the claims, which are intended to be construed without reference to any definitions that may be explicitly or implicitly included in any incorporated-by-reference materials.

What is claimed is:

1. A camera module, comprising:

- a first substrate having an upper surface and an opposing lower surface;
- a plurality of contacts disposed on the lower surface of the first substrate;
- a molded enclosure enclosing a gyroscopic sensor and an image stabilization logic module, said molded enclosure having an upper side and a lower side, said lower side being coupled to the upper surface of the first substrate;
- a second substrate having an upper surface and an opposing lower surface, said lower surface of the second substrate being coupled to the molded enclosure;
- an image sensor die coupled to the upper surface of the second substrate; and
- a lens module comprising a lens housing and at least one lens contained in the lens housing, said lens module being coupled to the upper surface of the second substrate.

2. The camera module of claim 1, wherein:

the image sensor die comprises a plurality of die contacts wire bonded to the upper surface of the second substrate.

3. The camera module of claim 1, further comprising a third substrate coupled to the first substrate and the second substrate.

4. A camera assembly, comprising:

- a substrate comprising a first portion and a second portion;

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an image sensor die coupled to the first portion of the substrate such that the image sensor die is disposed between the first and second portions of the substrate; an enclosure coupled between the first and second portions of the substrate, said image sensor die being contained within the enclosure; a plurality of camera components coupled to the substrate and disposed within the enclosure; and a lens module coupled to the first portion of the substrate.

5. The camera assembly of claim 4, wherein the second portion of the substrate comprises a main board contact region for coupling with circuit board contacts on a circuit board for an electronic device, said main board contact region being electrically coupled to the image sensor die via interconnects in the substrate.

6. The camera assembly of claim 4, wherein the enclosure comprises a transfer molding material enclosing the plurality of camera components.

7. A camera assembly, comprising:

a flexible substrate comprising a first portion and a second portion;

an image sensor die coupled to the first portion of the substrate, the image sensor die comprising a plurality of die contacts wire bonded to the substrate;

an enclosure coupled between the first and second portions of the substrate;

a plurality of camera components coupled to the substrate and disposed within the enclosure; and

a lens module coupled to the first portion of the substrate such that the image sensor die is positioned between the substrate and the lens module.

8. The camera assembly of claim 4, wherein:

the plurality of camera components are coupled to the first portion of the substrate adjacent the image sensor die and comprise a gyroscopic sensor and an image stabilization logic module.

9. The camera assembly of claim 4, wherein the plurality of camera components are coupled to the second portion of the substrate.

10. The camera assembly of claim 7, wherein:

the plurality of camera components are coupled to a first side of the first portion of the substrate; and

the image sensor die is coupled to a second side of the first portion of the substrate opposite the plurality of camera components.

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11. The camera assembly of claim 4, wherein the plurality of camera components comprises a gyroscopic sensor and an image stabilization logic module.

12. The camera assembly of claim 11, wherein the lens module comprises at least one lens, said camera assembly further comprising:

an actuator for translating the at least one lens or the image sensor die in response to control signals from the image stabilization logic module.

13. The camera assembly of claim 11, wherein:

the substrate further comprises a third portion between the first and second portions, said substrate being folded at a junction between the first portion and the third portion, and folded at a junction between the second portion and the third portion.

14. A method of forming a camera assembly, comprising: coupling a plurality of electronic components to a substrate having a first portion and a second portion; coupling an image sensor die to the substrate; coupling an enclosure to the first portion of the substrate to enclose the plurality of electronic components and the image sensor die; and

coupling the second portion of the substrate to the enclosure, thereby positioning the enclosure, the image sensor die, and the plurality of electronic components between the first and second portions of the substrate.

15. The method of claim 14, wherein said coupling the enclosure to the first portion of the substrate comprises forming a transfer mold enclosure on the first portion of the substrate to enclose the plurality of electronic components and the image sensor die.

16. The method of claim 14, wherein said coupling the image sensor die to the substrate comprises bonding an image sensor die to each substrate in an array of substrates in a substrate tape panel, said method further comprising:

after bonding the image sensor die to each substrate in the array of substrates, singulating each of the substrates from the array of substrates.

17. The method of claim 14, wherein the substrate comprises one or more of a high density interconnect (HDI) tape substrate or a polyimide tape substrate.

18. The method of claim 14, wherein:

the first portion of the substrate comprises an opening; and said bonding the image sensor die to the second portion of the substrate comprises bonding the image sensor die adjacent to the opening.

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